B Physics with Hadron Machines

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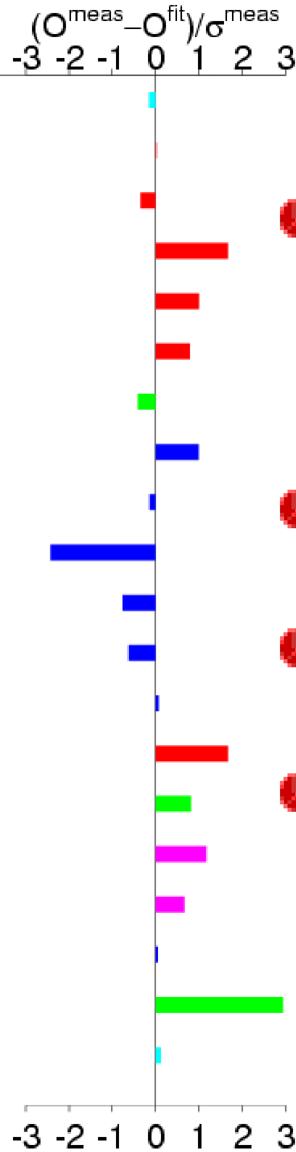
- **Introduction**
  - B hadron producers
- **The Past**
- **The Present: CDF & D0**
  - Selected results from Tevatron
- **The Future: BTeV & LHCb**
  - Status and prospects
- **Conclusion ....**

Current Understanding of Matter

	Measurement	Pull
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02761 ± 0.00036	-0.16
m_Z [GeV]	91.1875 ± 0.0021	0.02
Γ_Z [GeV]	2.4952 ± 0.0023	-0.36
σ_{had}^{0} [nb]	41.540 ± 0.037	1.67
R_l	20.767 ± 0.025	1.01
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.79
$A_l(P_\tau)$	0.1465 ± 0.0032	-0.42
R_b	0.21644 ± 0.00065	0.99
R_c	0.1718 ± 0.0031	-0.15
$A_{fb}^{0,b}$	0.0995 ± 0.0017	-2.43
$A_{fb}^{0,c}$	0.0713 ± 0.0036	-0.78
A_b	0.922 ± 0.020	-0.64
A_c	0.670 ± 0.026	0.07
A_l(SLD)	0.1513 ± 0.0021	1.67
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.82
m_W [GeV]	80.426 ± 0.034	1.17
Γ_W [GeV]	2.139 ± 0.069	0.67
m_t [GeV]	174.3 ± 5.1	0.05
$\sin^2\theta_W(\nu N)$	0.2277 ± 0.0016	2.94
Q_W(Cs)	-72.83 ± 0.49	0.12



- **The Standard Model is extremely successful description of the world of particle physics.**
- **Nobody seems satisfied with it.**
- **Too many free parameters?**
- **Leaves many important questions unanswered ....**

Flavour Changing Interactions in SM

Important questions about SM:

1. What is the origin of electroweak symmetry breaking?

   => Higgs mechanism

2. What is the origin of flavour symmetry breaking?

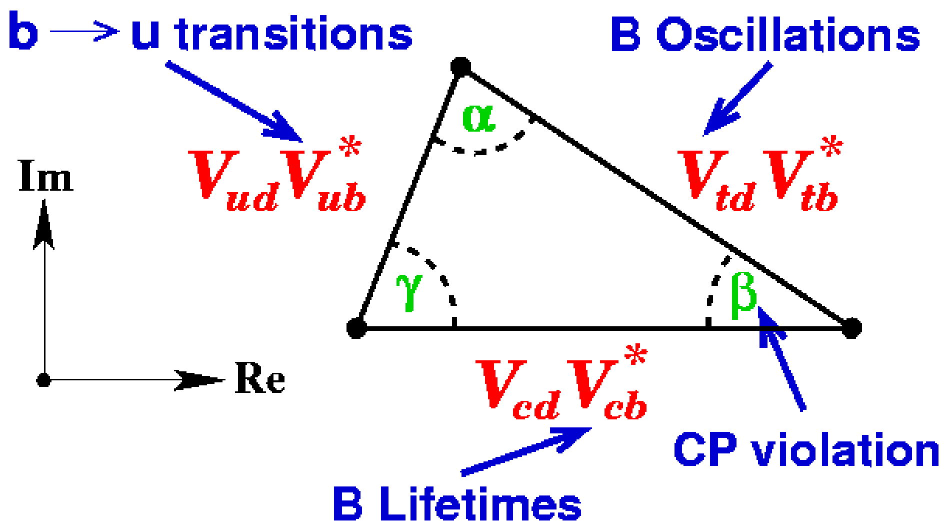
   => Quark mixing, CKM matrix

Flavour Changing Interactions:

- In SM flavour changing processes depend on CKM matrix
- Individual matrix elements not predicted by SM- must be measured by flavour changing interactions

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

B hadron decays measure
5 CKM matrix elements



Goal of present & future B physics:

- Test flavour changing interactions in all possible ways

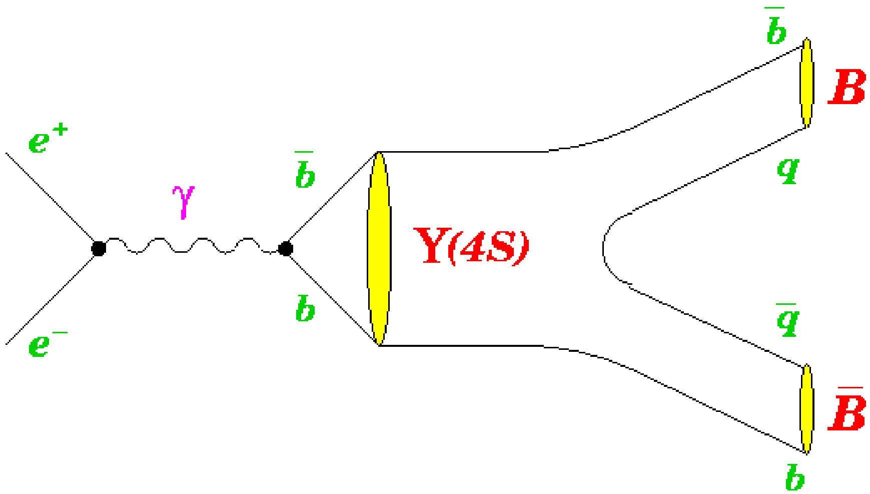
  => *Theoretically clean modes versus experimental accessibility*

- Measure sides and angles of CKM triangle in many ways

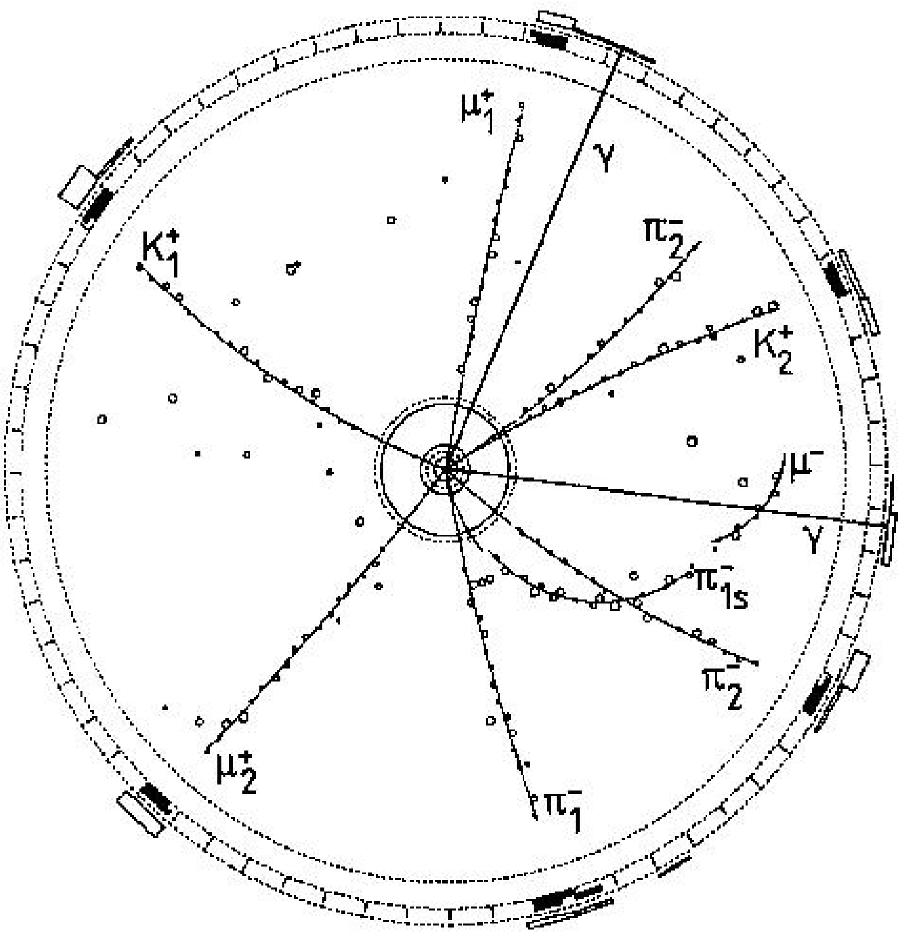
  => *Overconstrain triangle*

B Hadron Producers

$\Upsilon(4S)$: $e^+e^- \to \Upsilon(4S) \to B\bar{B}$



ARGUS:



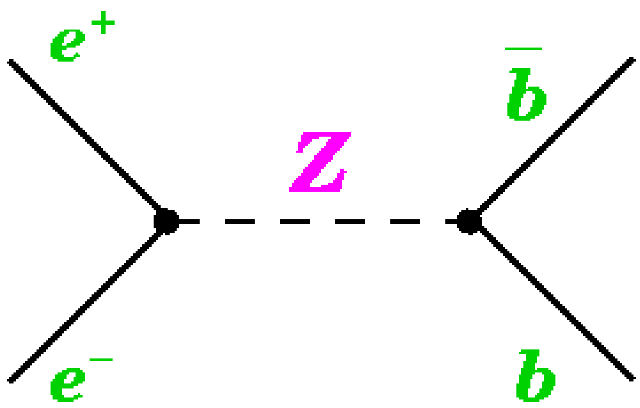
The Players:

ARGUS & CLEO (Pioneers)

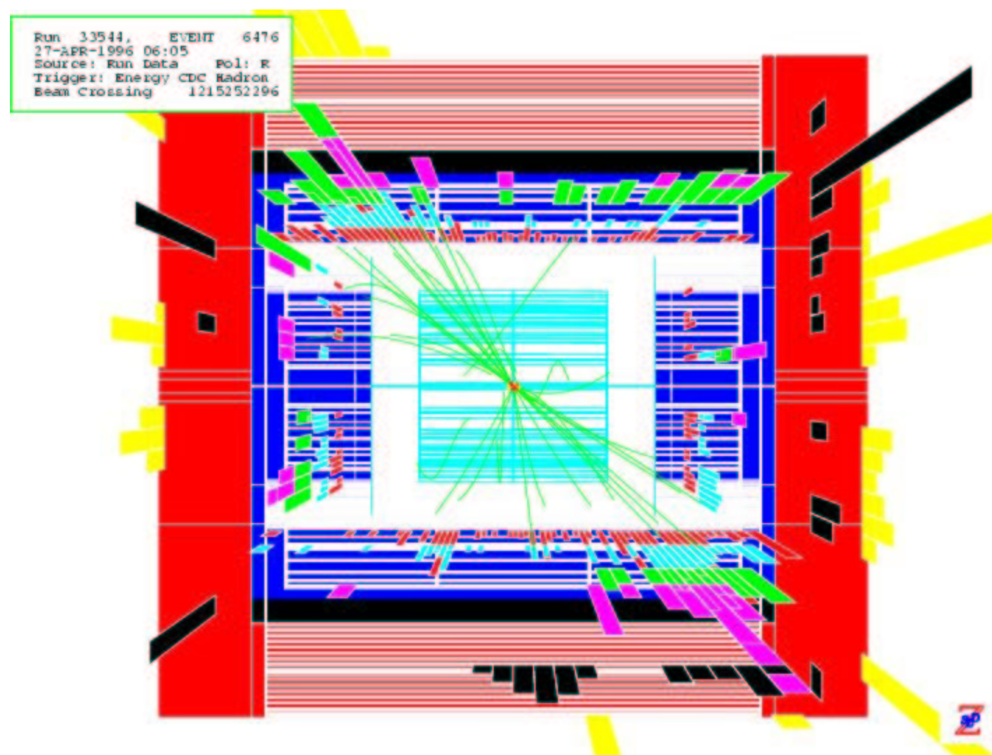
BaBar & Belle (B Factories)

B Hadron Producers

$\mathbf{Z^0}$: $e^+ e^- \rightarrow Z^0 \rightarrow b\bar{b}$



SLD:



The Players:

ALEPH, DELPHI, L3, OPAL

SLD

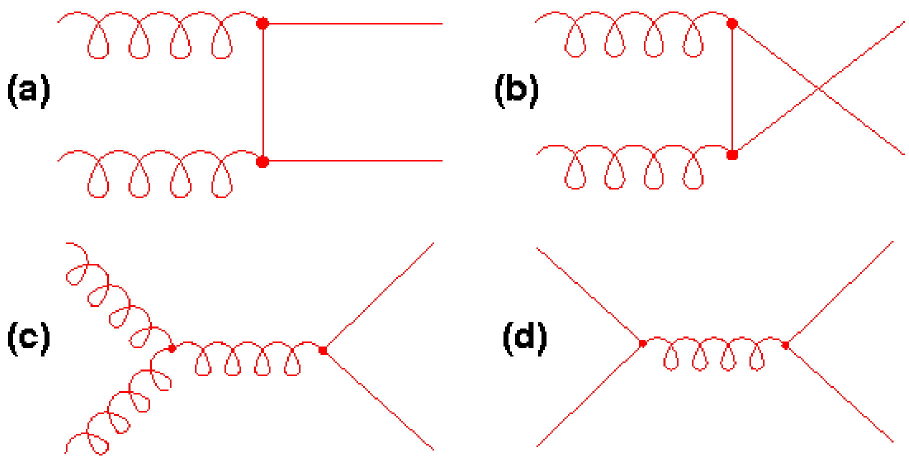
B Hadron Producers

Tevatron: $p\bar{p} \to b\bar{b}X$

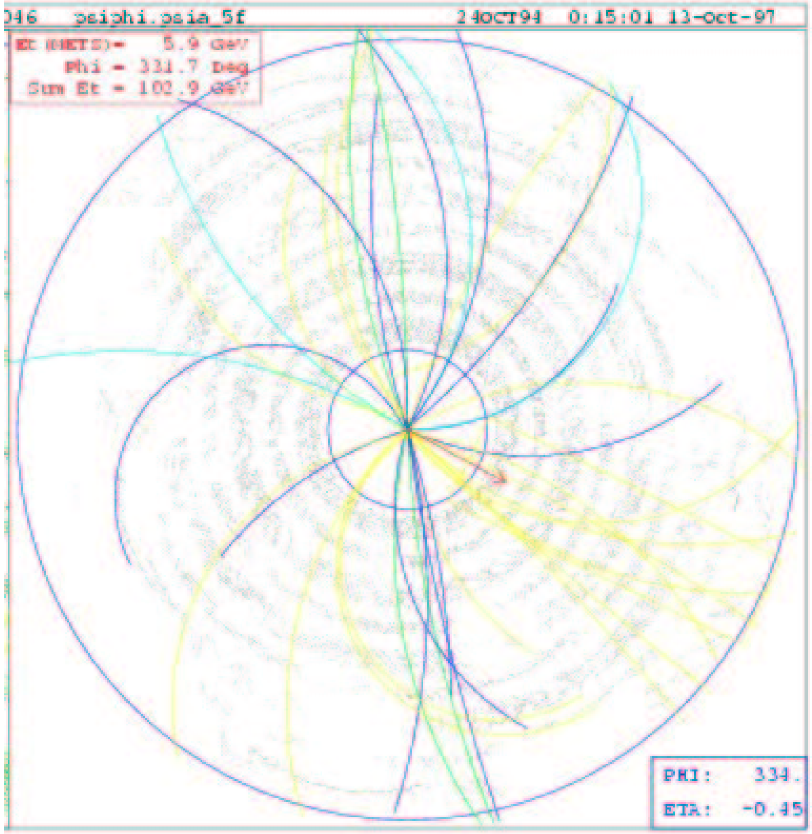
- Lowest order $\mathcal{O}(\alpha_s^2)$ diagrams for $b\bar{b}$ production

  (a)-(c) gluon-gluon fusion

  (d) quark-antiquark annihilation



CDF:



The Players:

CDF & D0

Other B producers: Hera-B, FNAL fixed target

The Future: Atlas, CMS, LHCb, BTeV

What's up with this (✈✱❀✖✌✇✿↕✪) dark energy in the universe?

Why the (✈✱▼✖✌✇↕✪) do we want to do B physics at a hadron machine ?

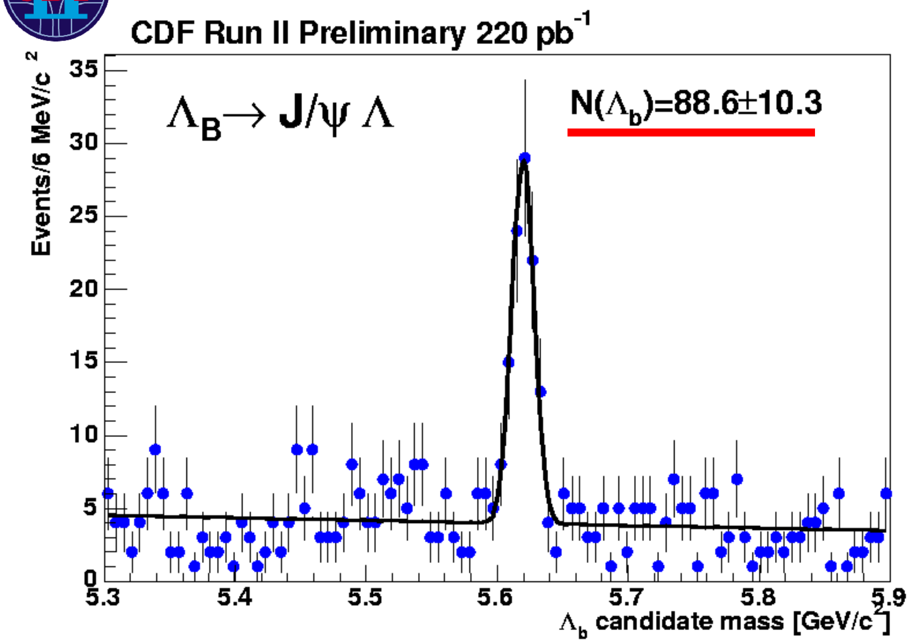
B Physics at Hadron Machines

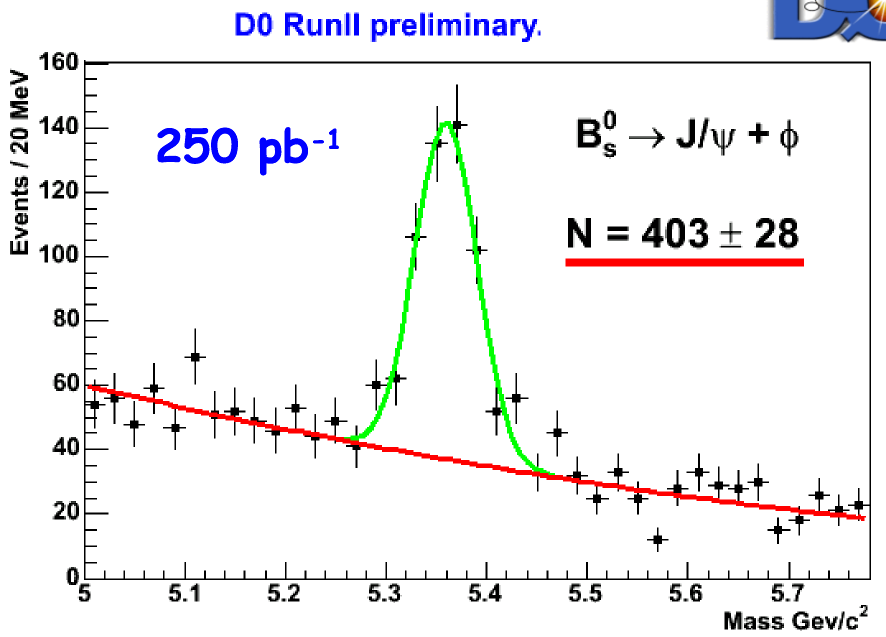
Advantages of B Physics at Hadron Machine:

All B hadrons are produced: $B^0, B^+, B_S^+, B_c^+, \Lambda_b^0$

Enormous cross section:

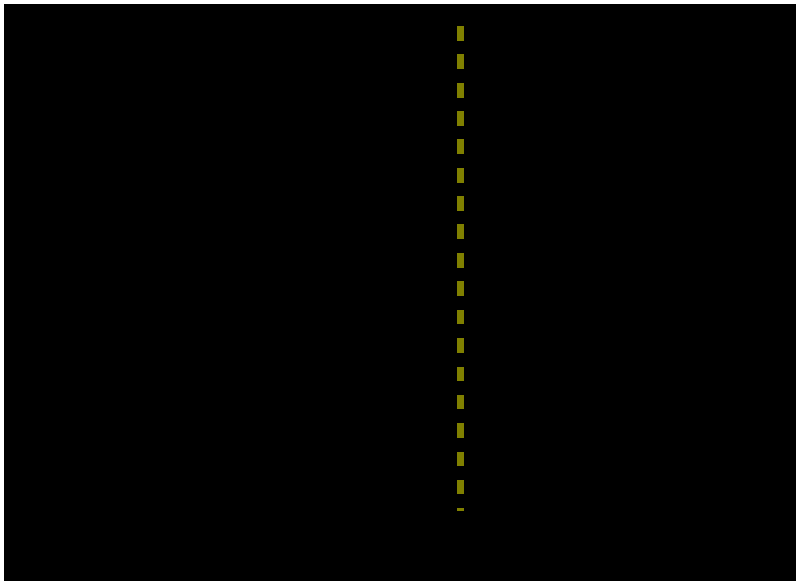
- **B-factory:** $\sigma(\Upsilon(4S) \to B\bar{B}) \sim 1 \text{ nb}$
- **Tevatron:** $\sigma(p\bar{p} \to b\bar{b}) \sim 100\ \mu\text{b}$





B Trigger at Hadron Machines

Comparison with charm production



- **Total inelastic cross section:**

  σ(total)/σ(b)~1000

➔ **It's all about the trigger!**

B Triggers:

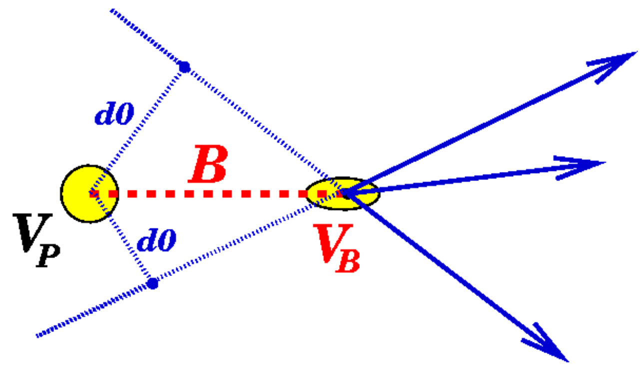
- **B trigger based on leptons**

  ➔ **Dilepton trigger: J/ψ, B mixing**

  ➔ **Single lepton: semileptonic B decays**

- **Hadronic track trigger (CDF)**

  (exploit 'long' B lifetime)



Level 1: Fast track trigger (XFT) finds charged track with p_T > 1.5 GeV/c

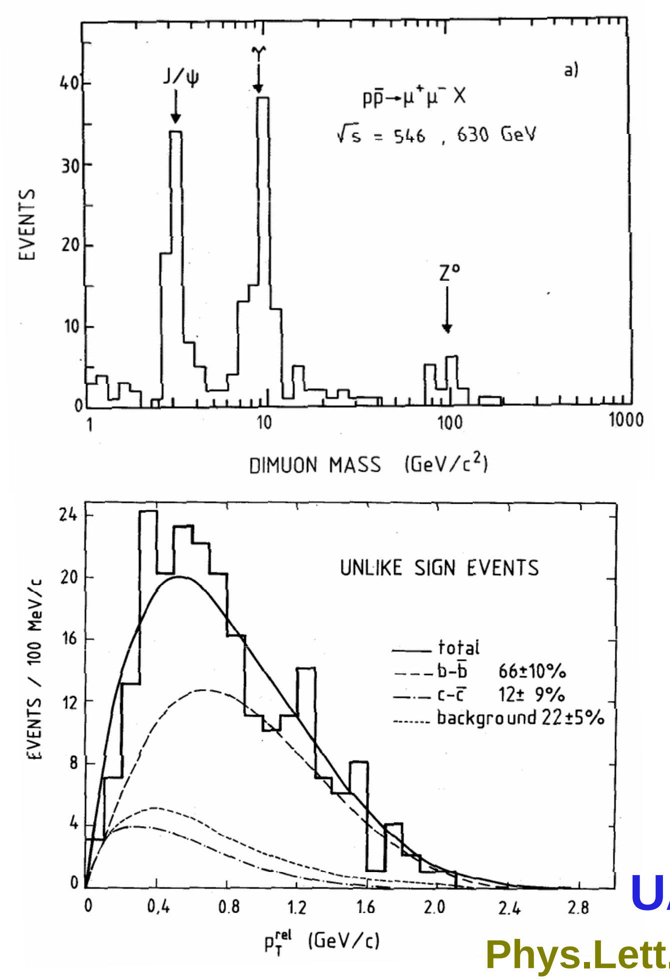
Level 2: Link tracks into silicon; require track impact parameter > 100 μm (SVT)

Access to hadronic B decays
=> B physics program fully competitive with B factories

The Past

A Brief History of Time

Beauty Production at UA1:
Observation of high-pT muon pairs from semileptonic decays of bb=

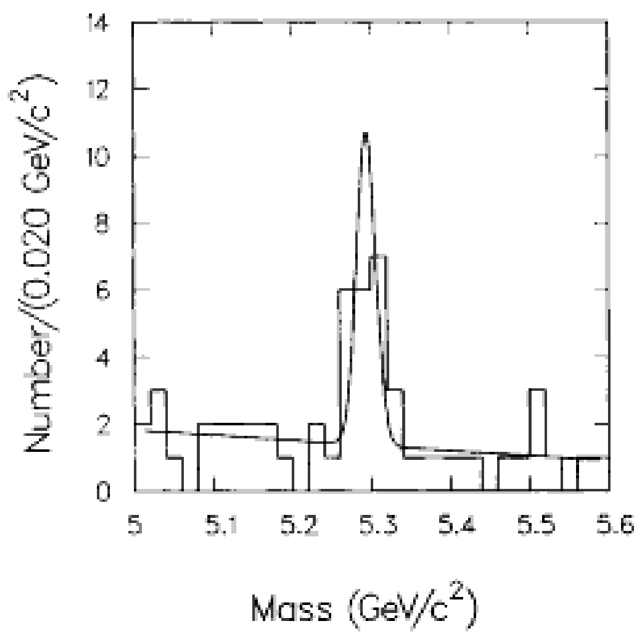


UA1 1987

Phys.Lett.B186,237(1987)

First fully reconstructed B mesons at a hadron collider:

$B^+ \to J/\psi\ K^+$

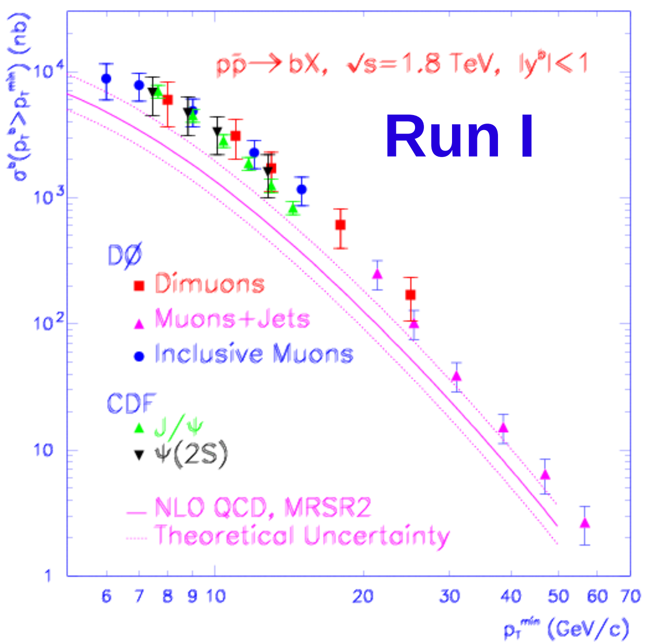


CDF 1992 (2.6 pb^{-1})

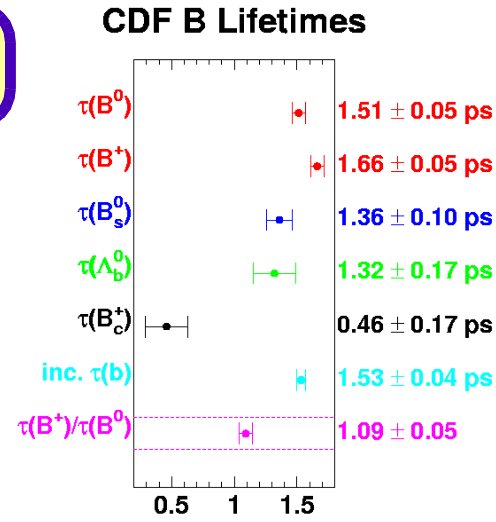
PRL 68, 3403 (1992)

B Physics in Run I

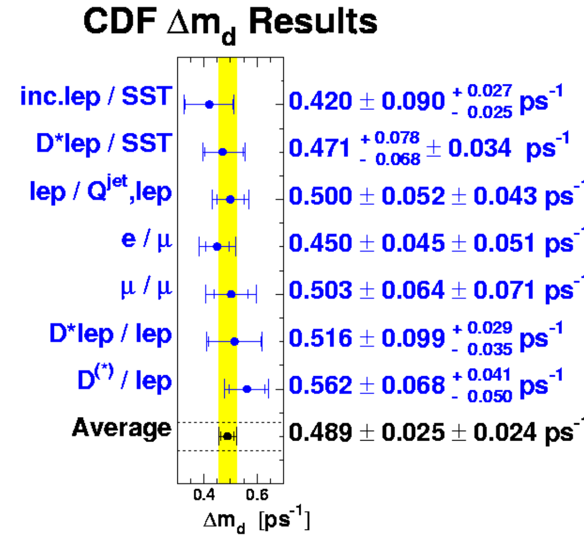
Successful B physics program at Tevatron in Run I:



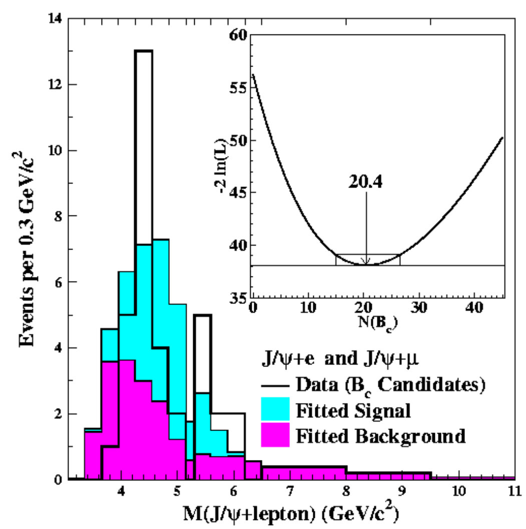
B Cross Sections



B lifetimes



B mixing



Discovery of B_C meson

Evidence for $\sin 2\beta \neq 0$

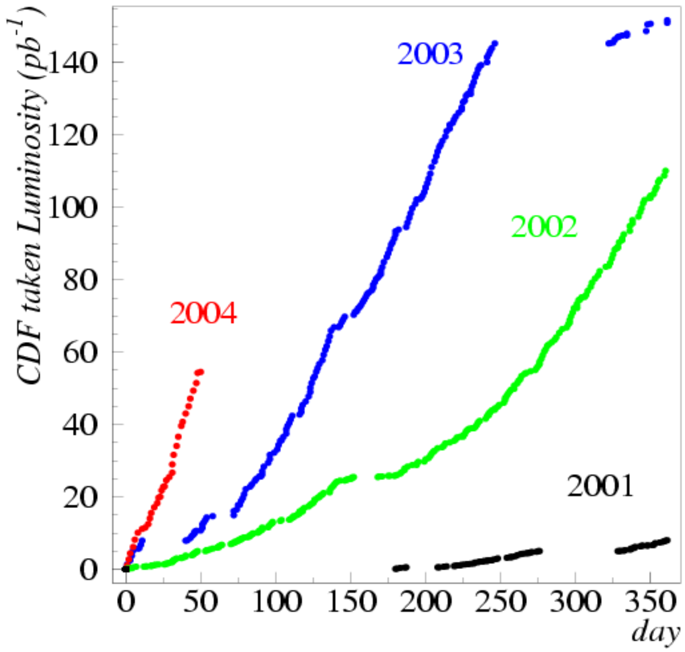
The Present

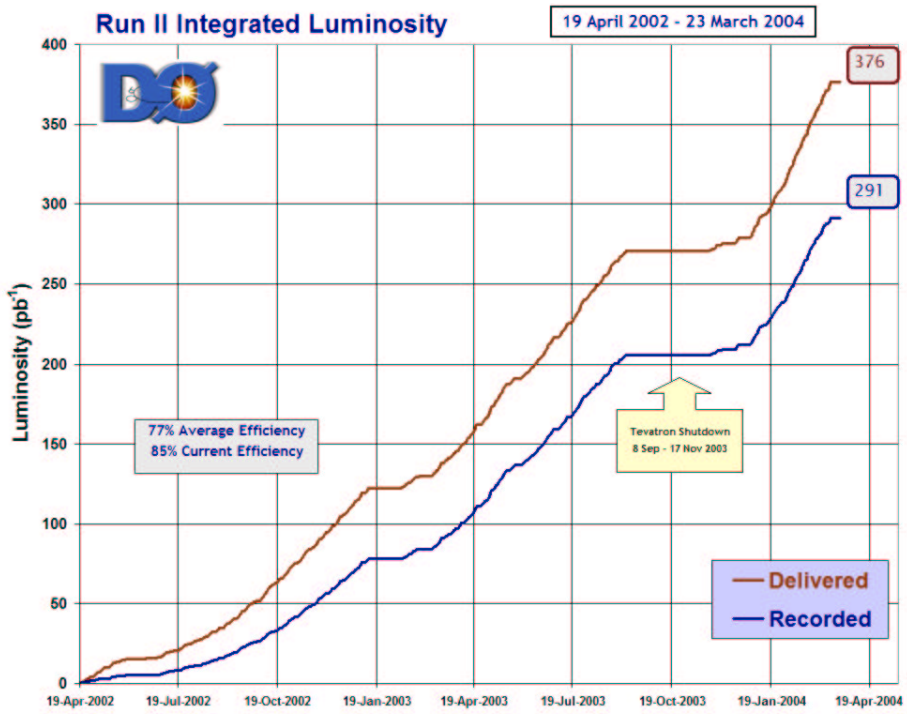
Tevatron Run II

Tevatron Performance:

- Tevatron has been working well in 2004
- Record initial luminosity = $= 7.2 \times 10^{31}\ \mathrm{sec}^{-1}\,\mathrm{cm}^{-2}$
- >300 pb^{-1} on tape
- ~100-250 pb^{-1} used for analysis

- CDF & D0 performing well
- Detector efficiency ~80-90%

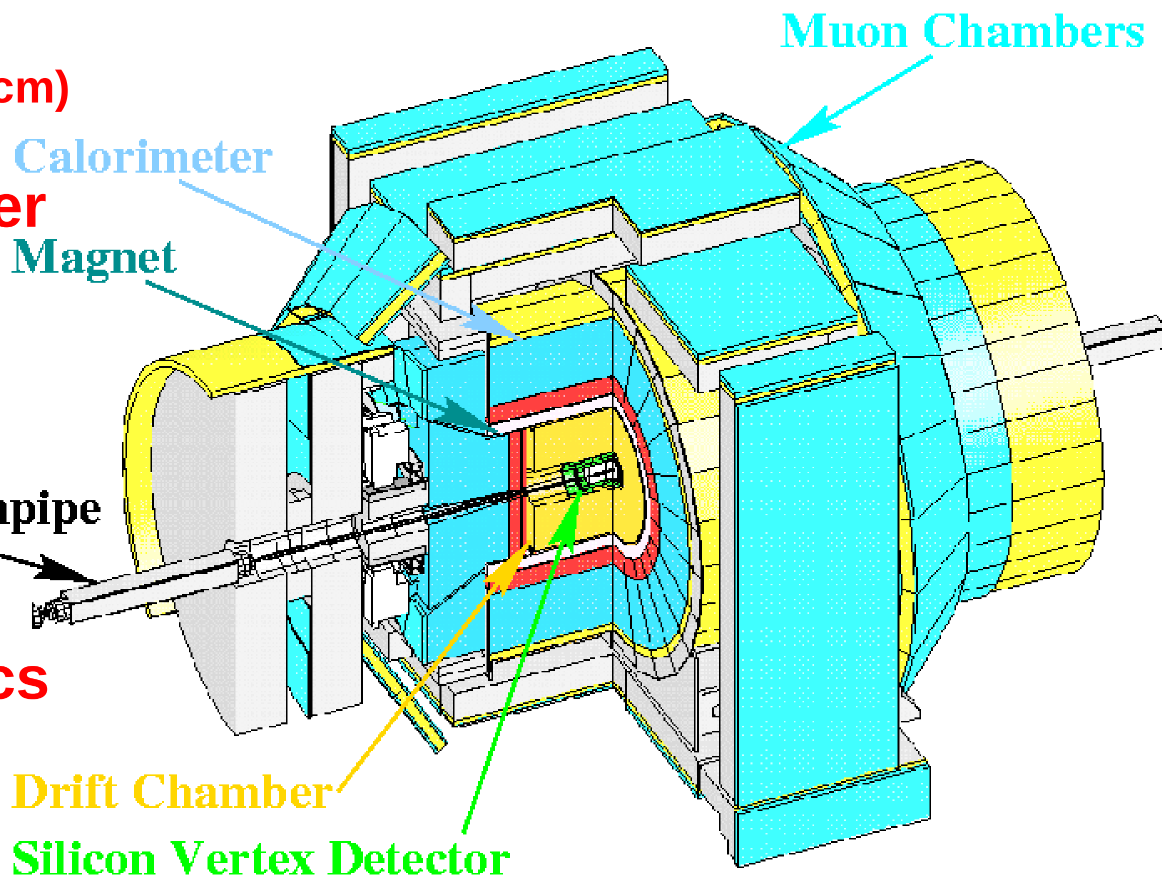




Run II: CDF Detector

The Upgraded CDF Detector:

- **Tracking upgrade:**
  - Silicon:
    Beampipe layer + 5 layers + 2/1 outer (forward) layers (radial 1.5 - 28 cm)
    Full coverage of luminous region; Si tracking up to $|\eta| < 2$
  - Central Outer Tracker:
    30,200 sense wires (44 - 132 cm)
    96 dE/dx samples
- **New endplug calorimeter**
- **Improved muon coverage**
- **Trigger/DAQ upgrade**
  - Fully pipelined
  - All digital (132 ns)
  - Silicon trigger at L2
- **New frontend electronics**
- **Time-of-flight system**

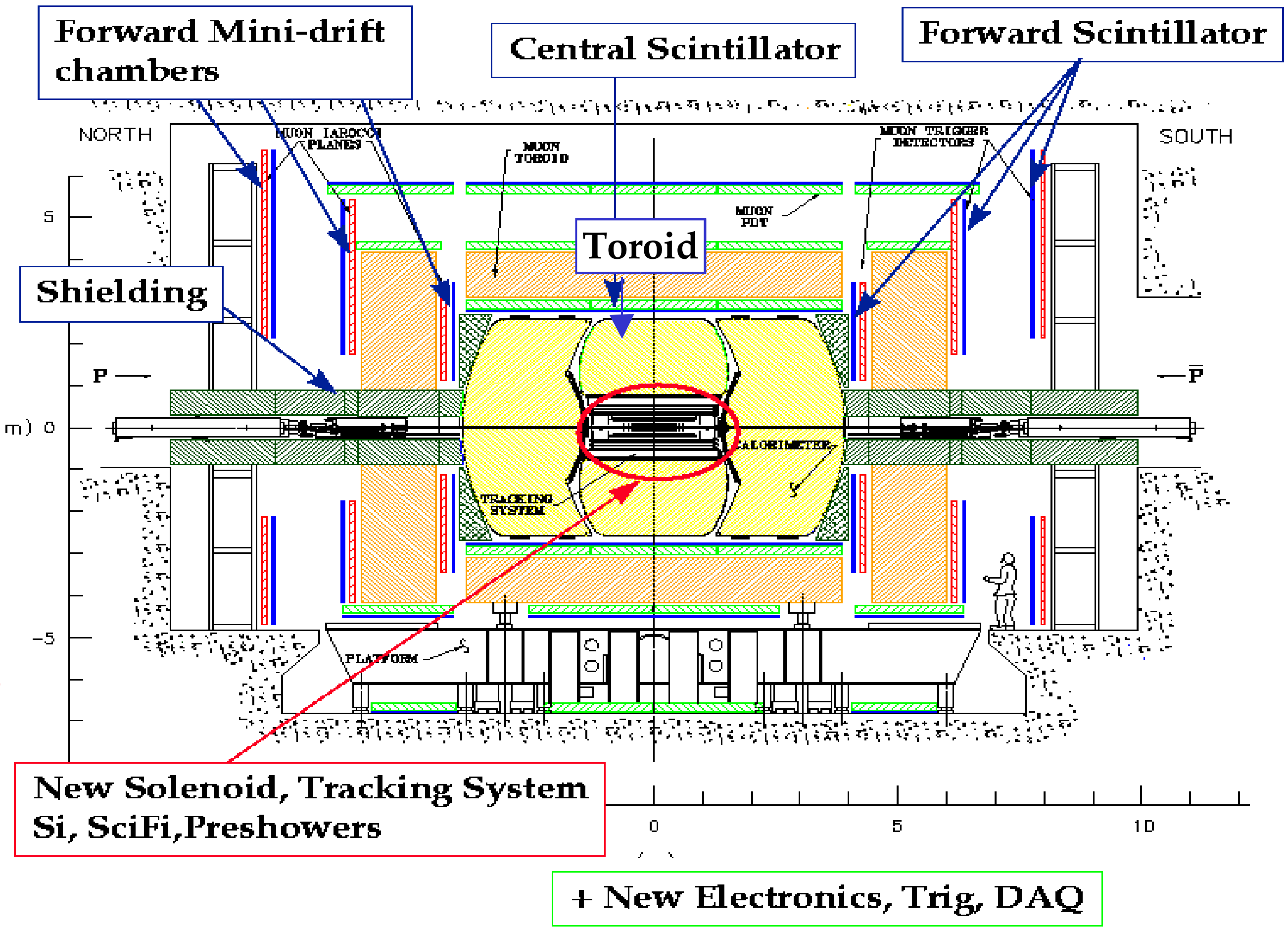


Run II: D0 Detector

The Upgraded D0 Detector:

What's new at D0:

- **New detector elements:**
  - solenoid, silicon tracker, fiber tracker
  - new preshower detector
- **Improved muon system**
- **Enhanced trigger system**
- **Extra shielding around beamlines**



Tevatron Results at APS 2004

List of CDF & D0 charm & bottom results at APS 2004:

- Observation of Semileptonic B Decays to Narrow D** Mesons
- Flavor Oscillations in Bd Mesons with OS Muon Tagging
- Bd mixing with Same Side Tagging
- Measurement of Lifetime Ratio for B0 and B+ Mesons
- Measurement of B Lifetimes in B->J/psi K Decays
- Observation of X(3872)
- Limit and Sensitivity for Rare Decay $B_s \to \mu\mu$
- Polarization Amplitudes in $B \to VV$
- BR and A_{CP} in $B^+ \to \phi K$
- B^0 Mixing with SST in Fully Reconstructed B Decays
- Study of Jet Charge Tagging
- Measurement of Hadronic Moments in Semileptonic B Decays
- Pentaquark Search in $\theta^+ \to pKs$
- Pentaquark Search in $\theta_c \to pD^*$
- Pentaquark Search for $\Xi(1860)$
- $B_s \to VV$ Lifetimes
- Measurement of B Hadron Masses
- Measurement of $BR(B^+ \to J/\psi\pi)$
- Observation and BR of $B_s \to \phi\phi$
- Search for $B_c \to J/\psi\mu X$
- Soft-Electron Reconstruction for $B_c \to J/\psi eX$
- BR and A_{CP} in $D^+ \to \pi^+\pi^-\pi^+$

(List might be incomplete)

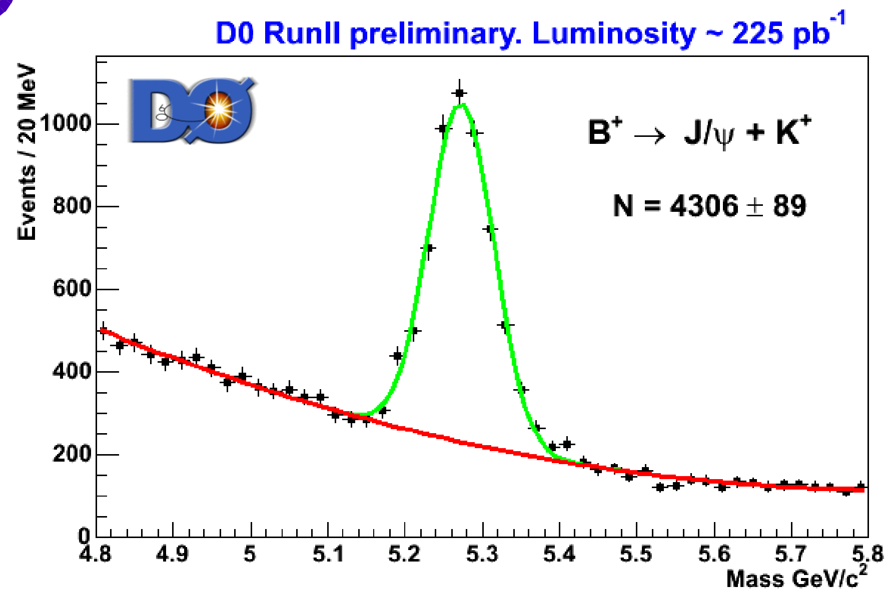
Selected Run II Results

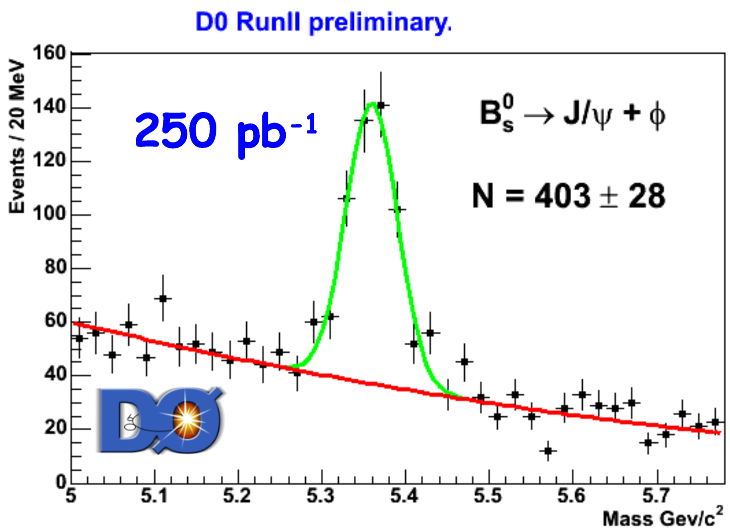
Exclusive B Decays:

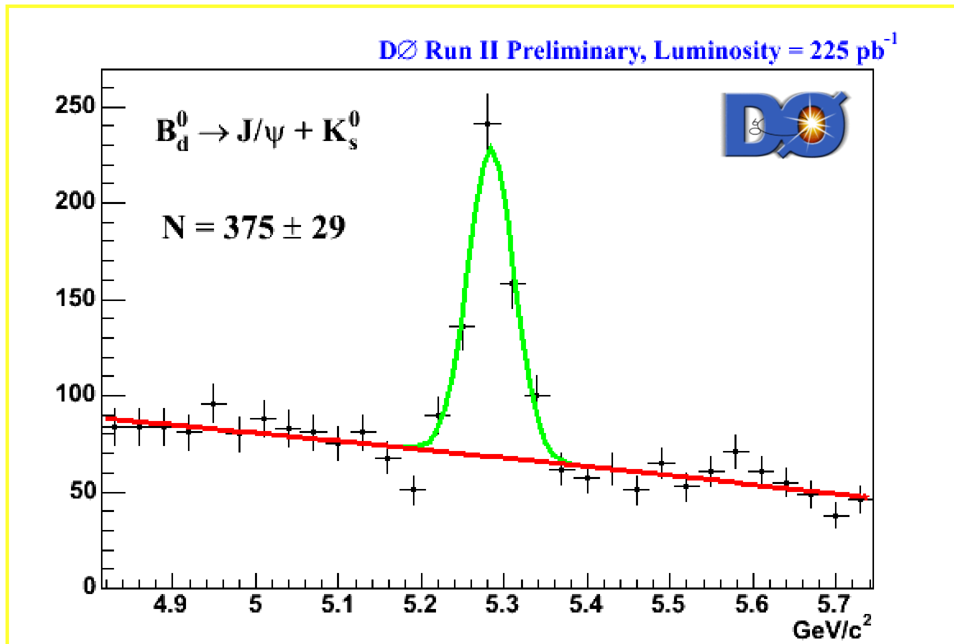
Accumulate large samples of fully reconstructed B hadrons:

DØ finds in 250 pb^{-1}:

$B^+ \to J/\psi K^+$ (N ~ 4300)
$B^0 \to J/\psi K^0_S$ (N ~ 375)
$B^0 \to J/\psi K^{*0}$ (N ~ 1900)
$B^0_s \to J/\psi \phi$ (N ~ 400)
$\Lambda_b \to J/\psi \Lambda$ (N ~ 52)







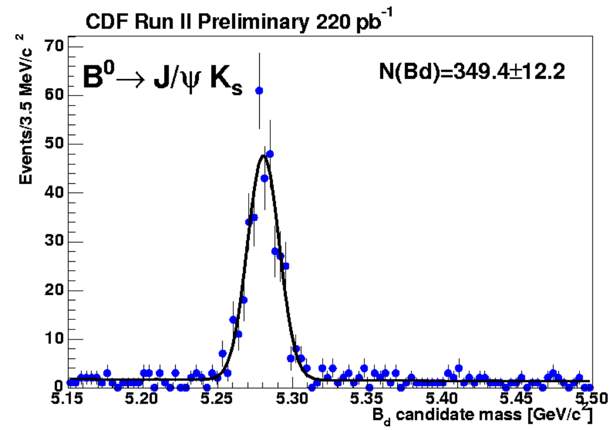
Selected Run II Results

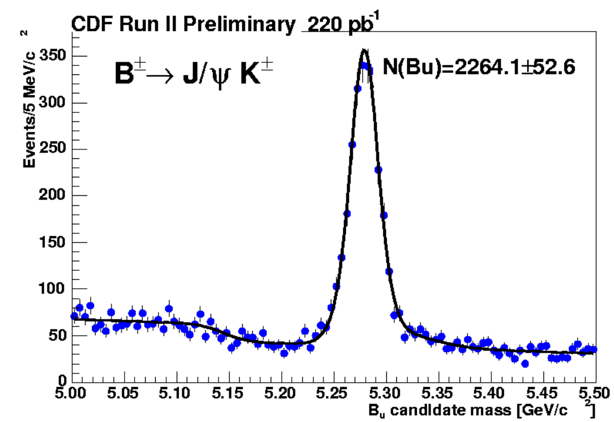
Exclusive B Decays:

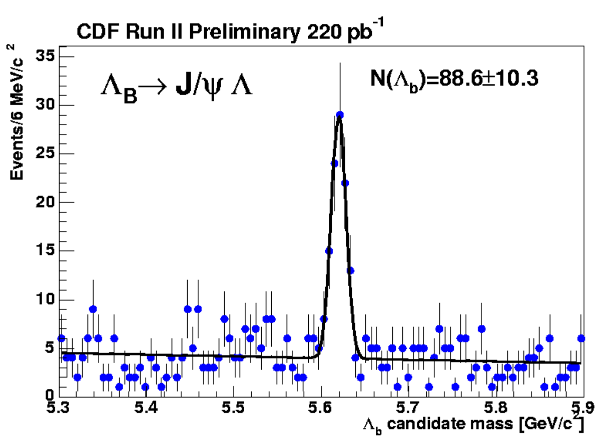
Precision mass measurements from exclusive B -> J/ψ X

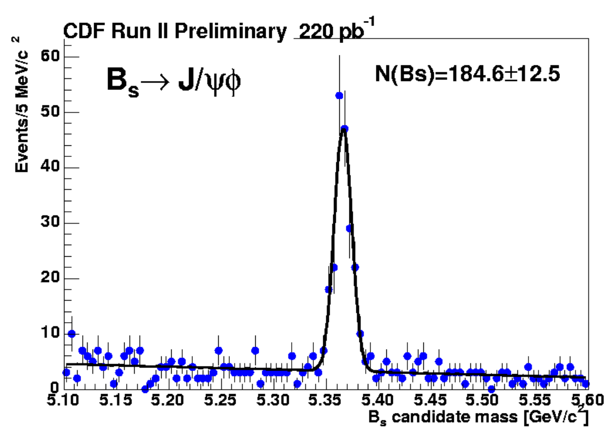
$$m(B^+) = (5279.10 \pm 0.41 \pm 0.34)\ \mathrm{MeV}/c^2$$
$$m(B^0) = (5279.57 \pm 0.53 \pm 0.30)\ \mathrm{MeV}/c^2$$
$$m(B_s^0) = (5366.01 \pm 0.73 \pm 0.30)\ \mathrm{MeV}/c^2$$
$$m(\Lambda_b) = (5619.7 \pm 1.2 \pm 1.2)\ \mathrm{MeV}/c^2$$

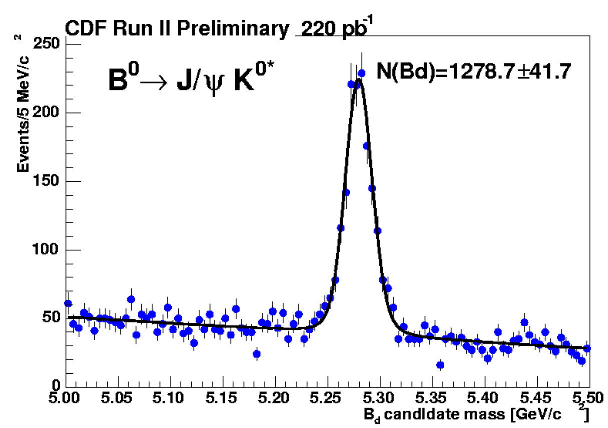
(current world best values)











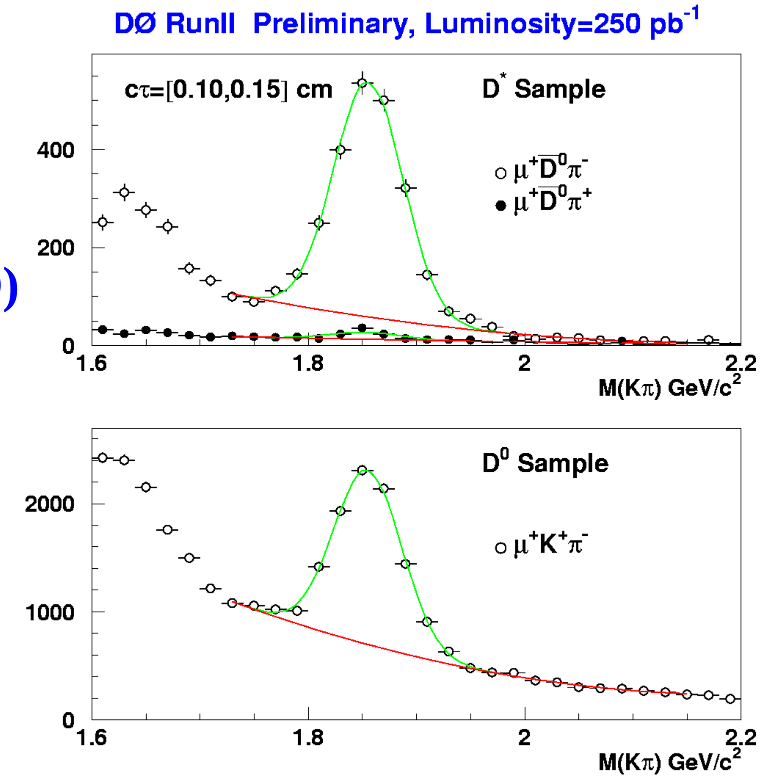
B Lifetimes

$\tau(B^+)/\tau(B^0)$ from Semileptonic Decays

Novel Analysis Technique

- Measure directly lifetime ratio instead of indivdual lifetimes
- Make use of: D* mainly from B^0,
  D^0 mainly from B^+
  - ▲ - Group events into 8 bins of
  - ▲ Visible Proper Decay Length:
  - ▲ - Measure $r = N(\mu D^*)/N(\mu D^0)$ in each bin
    - In both cases fit D^0 signal to extract $N(\mu D)$
    - Use slow pion only to distinguish B^0 from B^+ (no lifetime bias)
- Account for feed-down from D** using MC

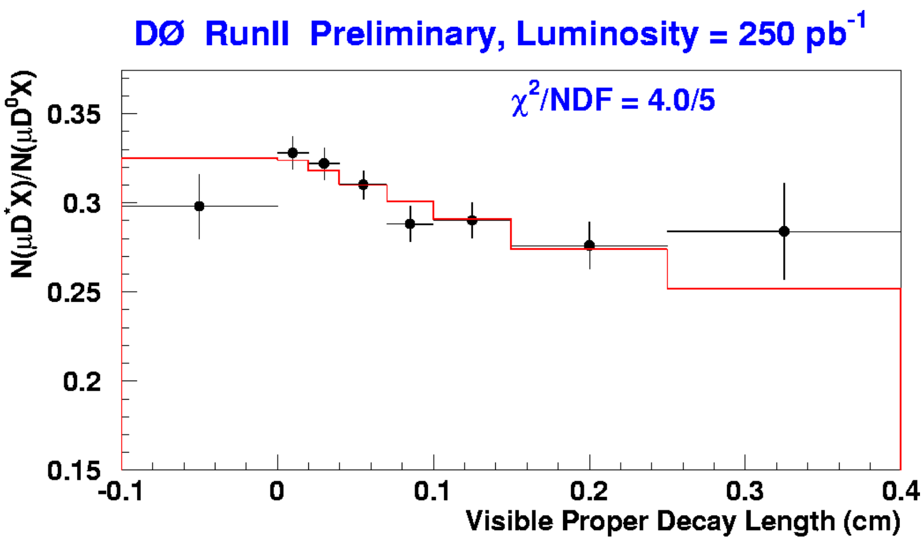
one example : VPDL bin [0.10 - 0.15 cm]



B Lifetimes

$\tau(B^+)/\tau(B^0)$ Lifetime Ratio

Use binned χ^2 fit of event ratios to determine $\tau(B^+)/\tau(B^0)$



D0 Preliminary result:
$\tau(B^+)/\tau(B^0)$ = 1.093 ± 0.021 ± 0.022

Extremely competitive with B factories

Lifetimes from excl. B -> J/ψ K

Use fully rec. B decays

$c\tau_{Bu}$ = 498.1±9.9(stat)±2.4(syst)

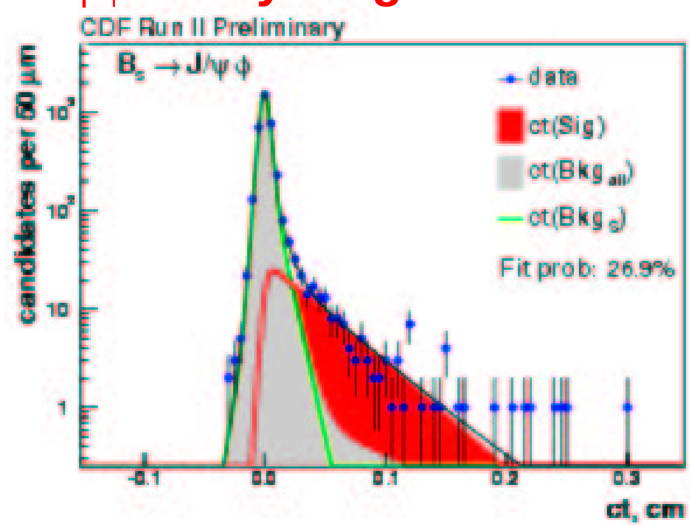
$c\tau_{Bd}$ = 461.3±15.4(stat)±2.4(syst)

$c\tau_{Bs}$ = 410.4±30.0(stat)+2.4-2.9(syst)

τ_{Bu}/τ_{Bd} = 1.080 ± 0.042

τ_{Bs}/τ_{Bd} = 0.890 ± 0.072

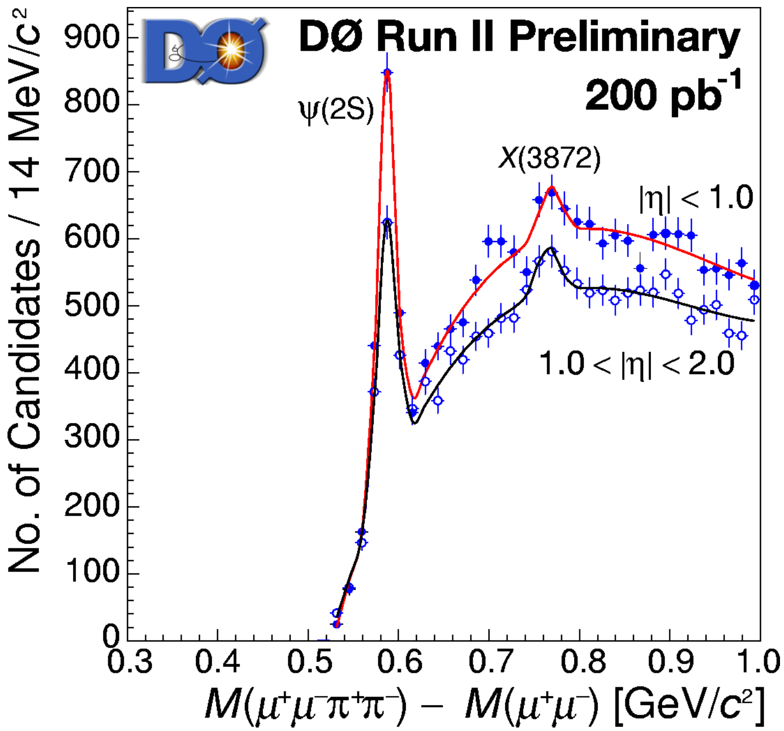
B_s->J/$\psi\phi$ decay length



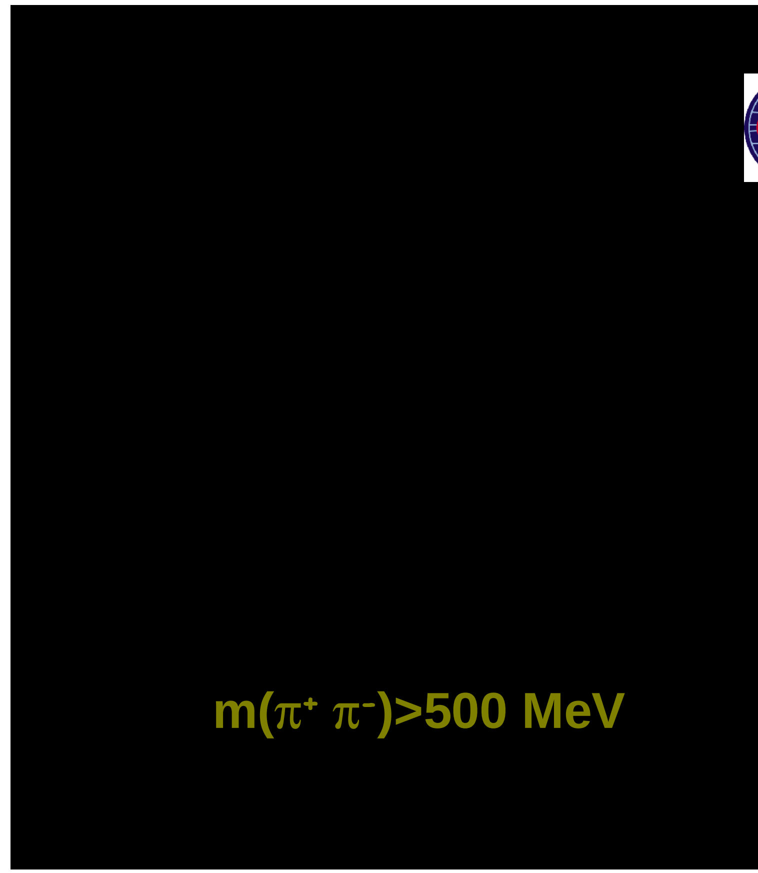
$X(3872) \rightarrow J/\Psi\ \pi^+ \pi^-$

Aug. 2003, Belle announced new particle at m~3872 MeV/c²
Observed in B⁺ decays: $B^+ \to K^+ X(3872)$, $X(3872) \rightarrow J/\Psi\ \pi^+ \pi^-$
$N = 35.7 \pm 6.8$, $m = (3872.0 \pm 0.6 \pm 0.5)$ MeV/c^2

X(3872) confirmed by CDF & D0:

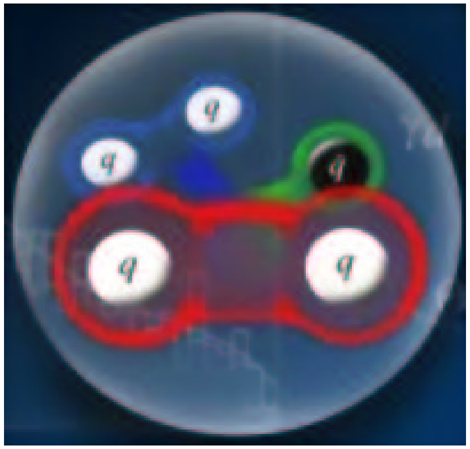


$N = 300 \pm 61$
$\Delta m = (768 \pm 4 \pm 4)$ MeV/c^2



$N = 730 \pm 90$
$m = (3871.3 \pm 0.7 \pm 0.4)$ MeV/c^2

Pentaquarks



Five quark state: 4 quarks + 1 anti-quark

flavour (anti-quark) $\neq$ flavour(quarks)

Predicted by Diakonov, Petrov, Polyakov (1997)

States observed so far:

$\Theta^+ : |u\,u\,d\,d\,\bar{s}\rangle$

$\Xi^{--} : |s\,s\,d\,d\,\bar{u}\rangle \qquad \Xi^0 : |\bar{s}\,\bar{s}\,\bar{d}\,d\,\bar{u}\rangle$

$\Theta_c^0 : |u\,u\,d\,d\,\bar{c}\rangle$

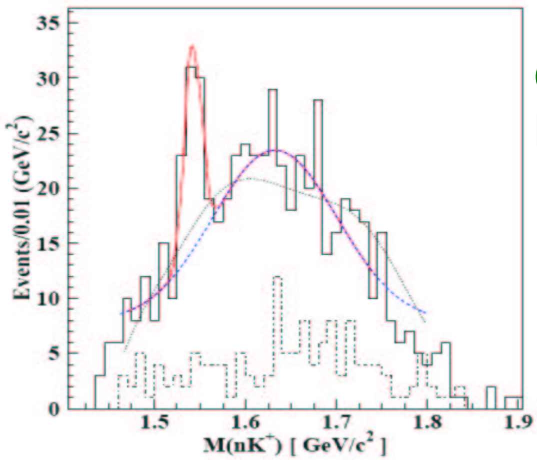
Discuss first: Θ^+

mass ~ 1530 MeV, width < 15 MeV

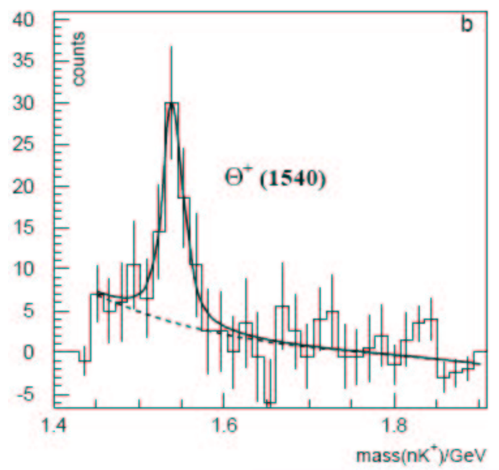
Decays equally to nK^+ and pK^0

Pentaquarks

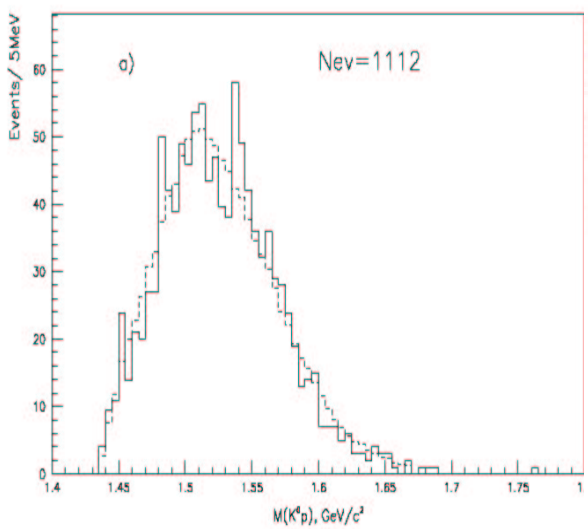
Θ^+: Reported evidence in nK^+



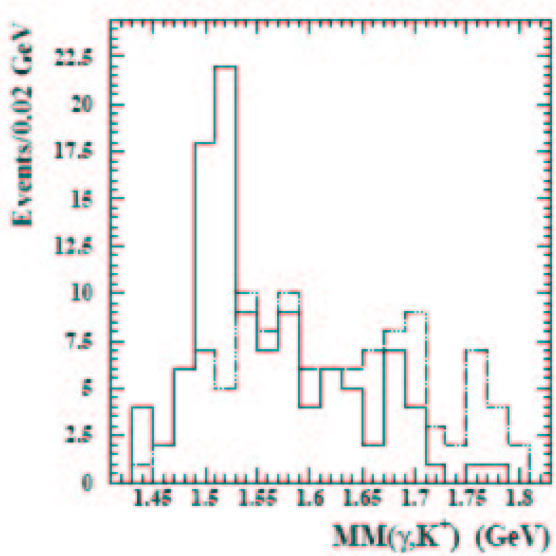
CLAS
hep-ex0307018



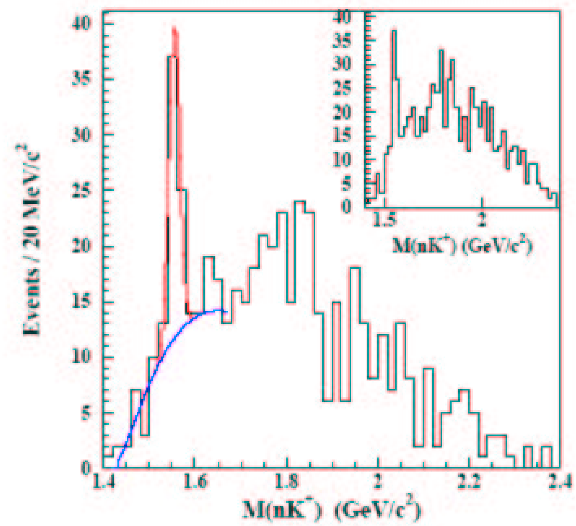
SAPHIR
hep-ex0307083



DIANA hep-ex0304040



LEPS hep-ex0402005

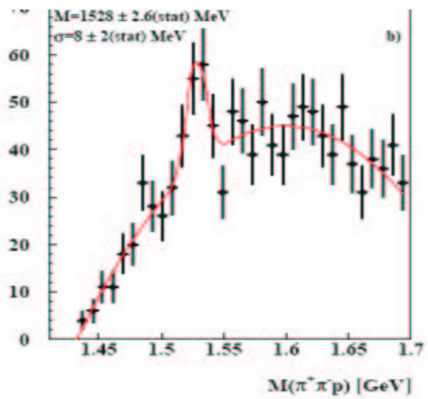


CLAS-2 hep-ex0402005

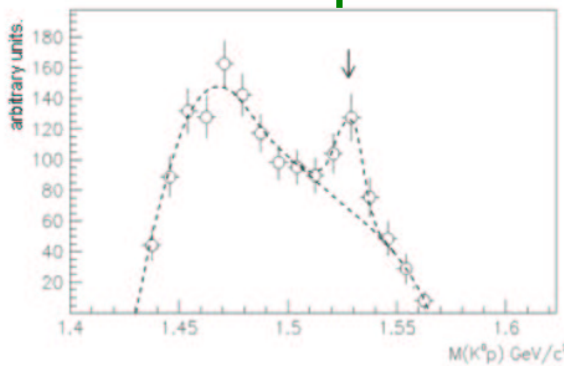
Pentaquarks

Θ^+: Reported evidence in pK^0

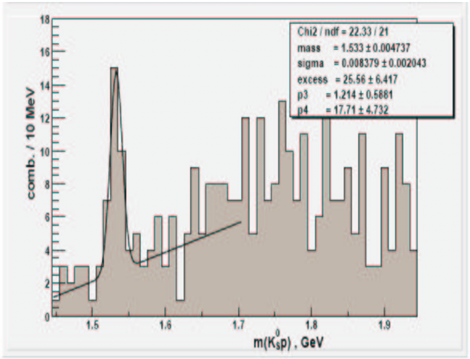
HERMES hep-ex0312044

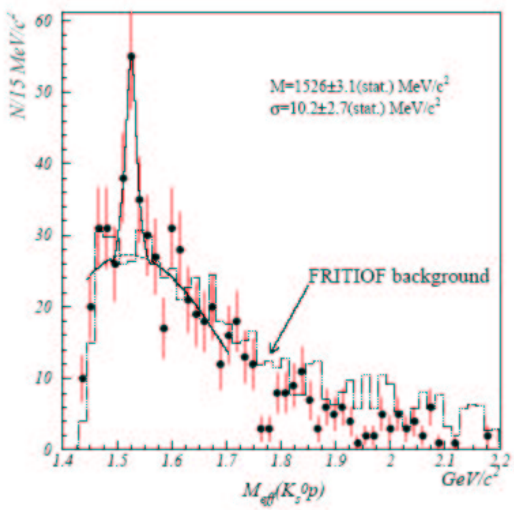


COSY-TOF hep-ex0403011

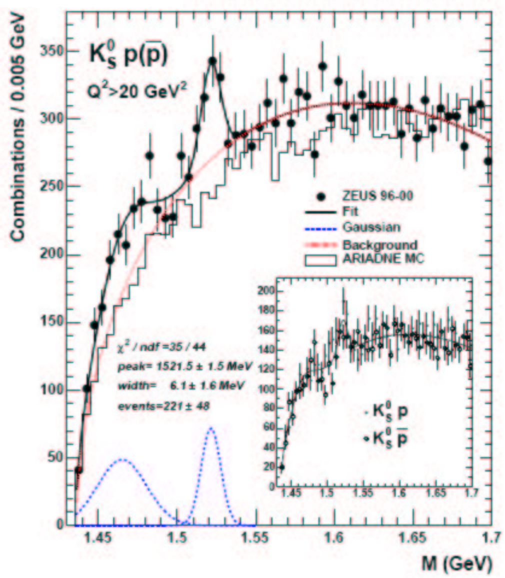


Asratyan et al.hep-ex0309042





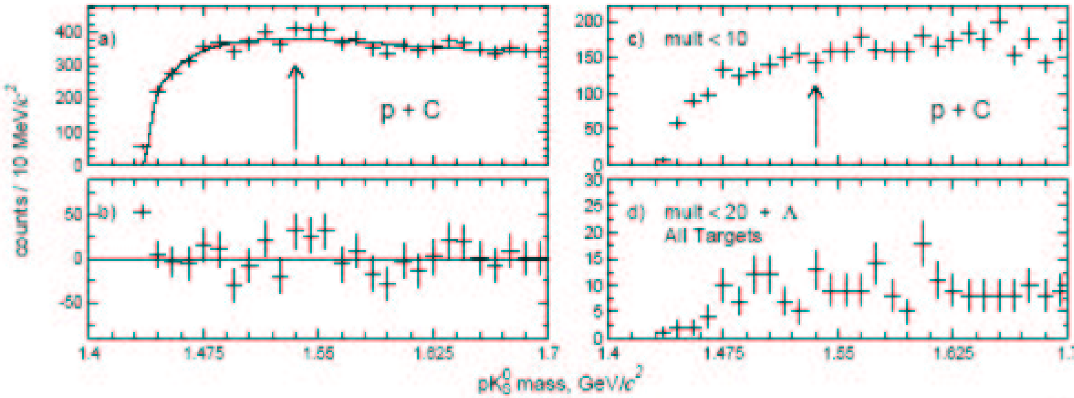
SVD
hep-ex0401024



ZEUS
hep-ex0403051

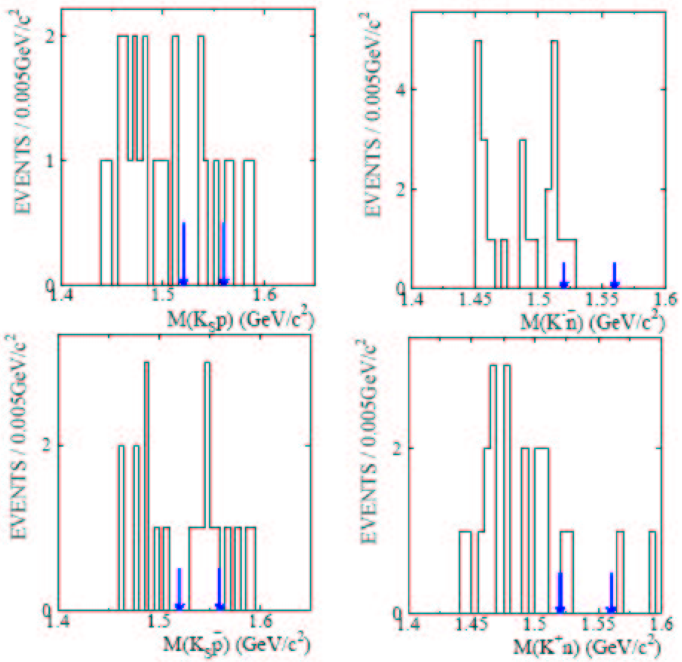
Pentaquarks

Θ^+: Reported negative evidence

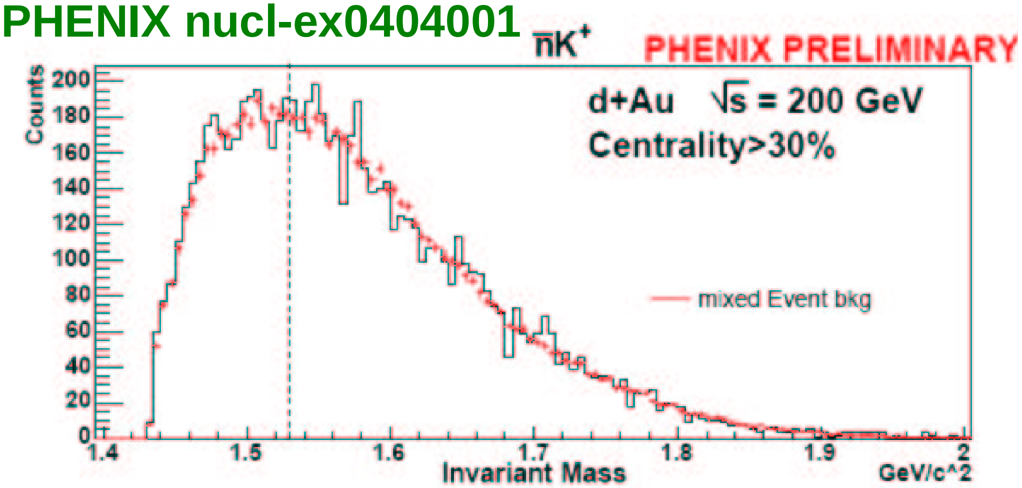


HERA-B hep-ex0403020

BES hep-ex0402012



PHENIX nucl-ex0404001

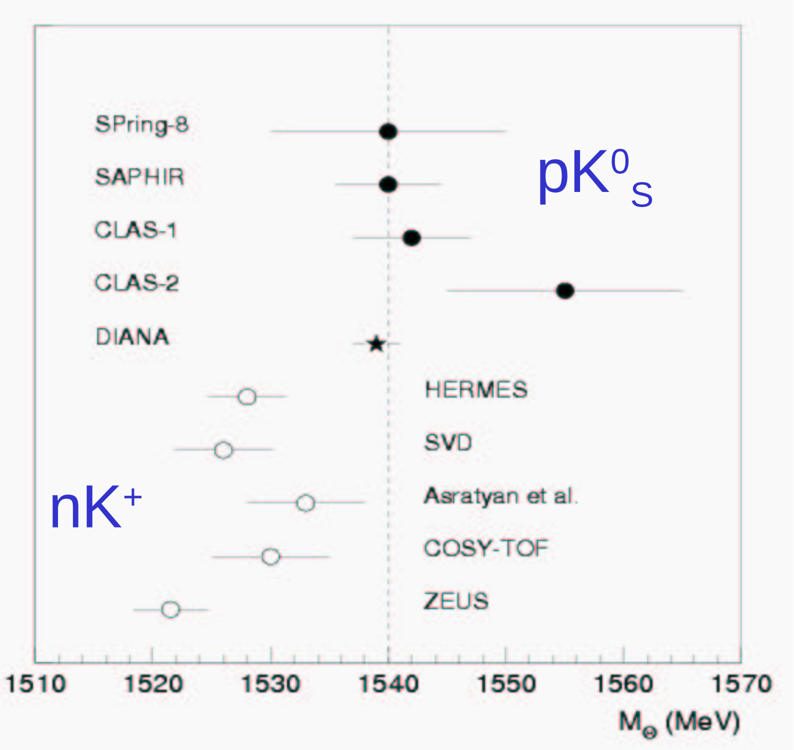


Pentaquarks

Θ^+: **Summary of evidence**
10 pos., 3 neg. reports
masses consistent?

Search at Tevatron

Experiments	Mass (MeV)	Width (MeV)	Observation
SPring-8 [6]	1540 ± 10	< 25	nK^+
SAPHIR [7]	$1540 \pm 4 \pm 2$	< 25	nK^+
CLAS-1 [8]	1542 ± 5	< 21	nK^+
CLAS-2 [9]	1555 ± 10	< 26	nK^+
DIANA [10]	1539 ± 2	< 9	$K^+n \to K^0_S p$
HERMES [11]	$1528 \pm 2.6 \pm 2.1$	$17 \pm 9 \pm 3$	pK^0_S
SVD [13]	$1526 \pm 3 \pm 3$	< 24	pK^0_S
Asratyan *et al.* [12]	1533 ± 5	< 20	pK^0_S
ZEUS [14]	$1521.5 \pm 1.5\ ^{+2.8}_{-1.7}$	$6.1 \pm 1.6\ ^{+2.0}_{-1.4}$	pK^0_S, $\bar{p}K^0_S$
COSY-TOF [15]	1530 ± 5	$< 18 \pm 4$	$pp \to \Sigma^+ pK^0_S$



All signals in 3-6 σ range

Pentaquarks at CDF

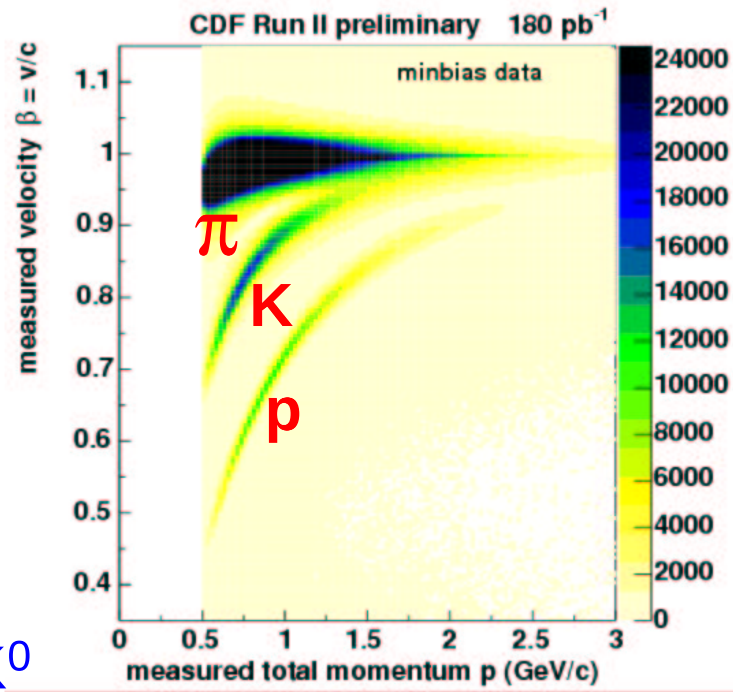
Search for $\Theta^+ \rightarrow pK^0_S \rightarrow p\pi^+\pi^-$

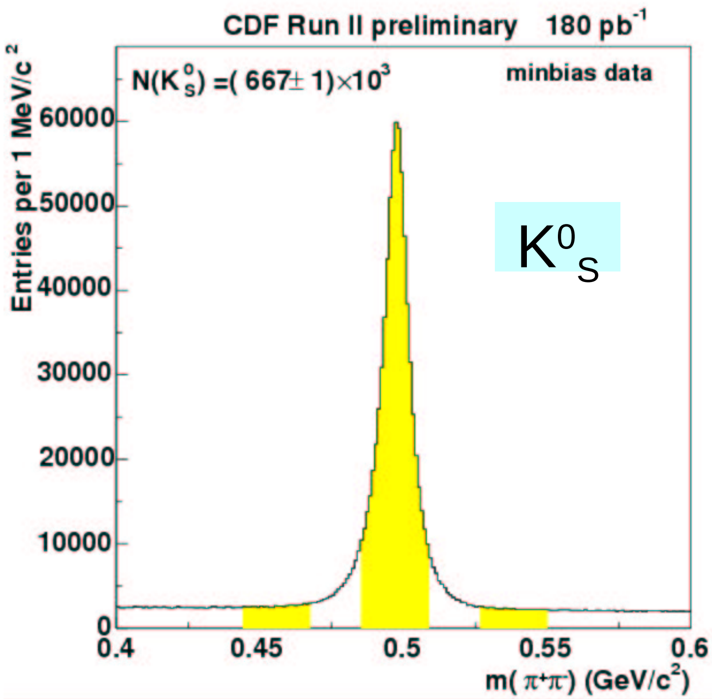
Use 2 energy ranges:

min.bias (23mio), jet20 (16mio)

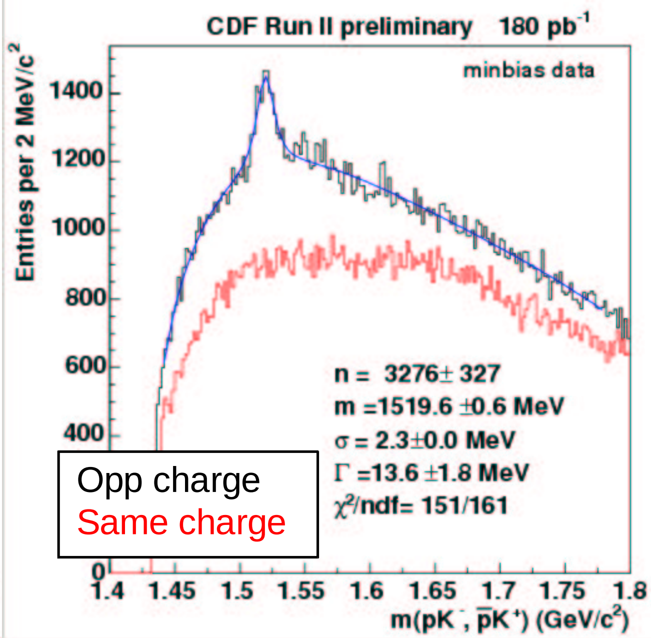
Identify protons with ToF

Reconstruct reference states

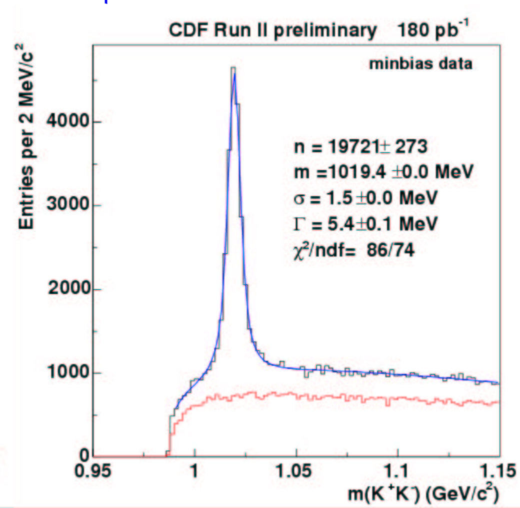




$\Lambda(1520) \rightarrow pK^0$

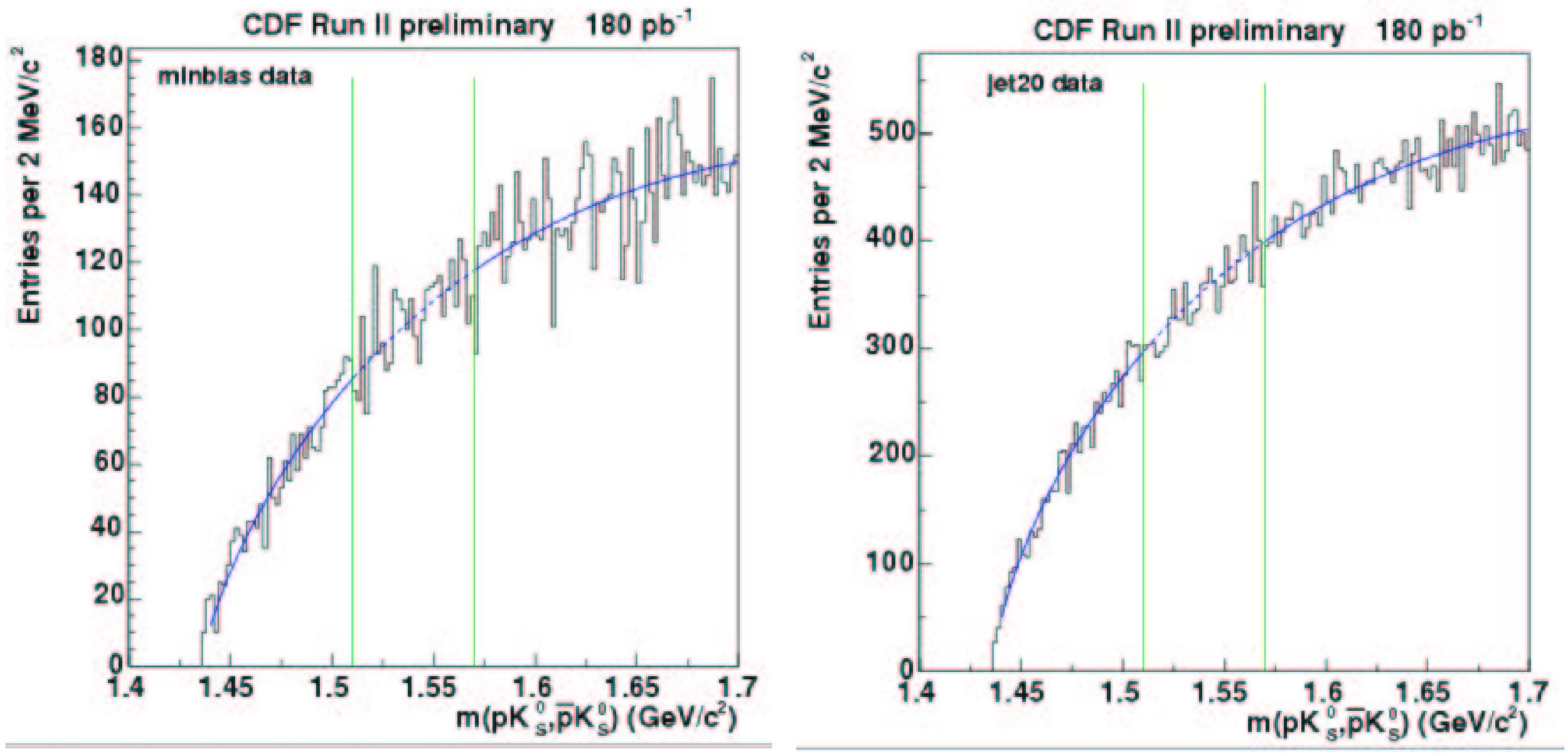


$\phi \rightarrow KK$



Pentaquarks at CDF

Search for $\Theta^+ \rightarrow pK_S^0 \rightarrow p\,\pi^+\pi^-$



No evidence at CDF for narrow resonance

CDF is working on limit for $\sigma(\Theta^+/\Lambda(1520))$

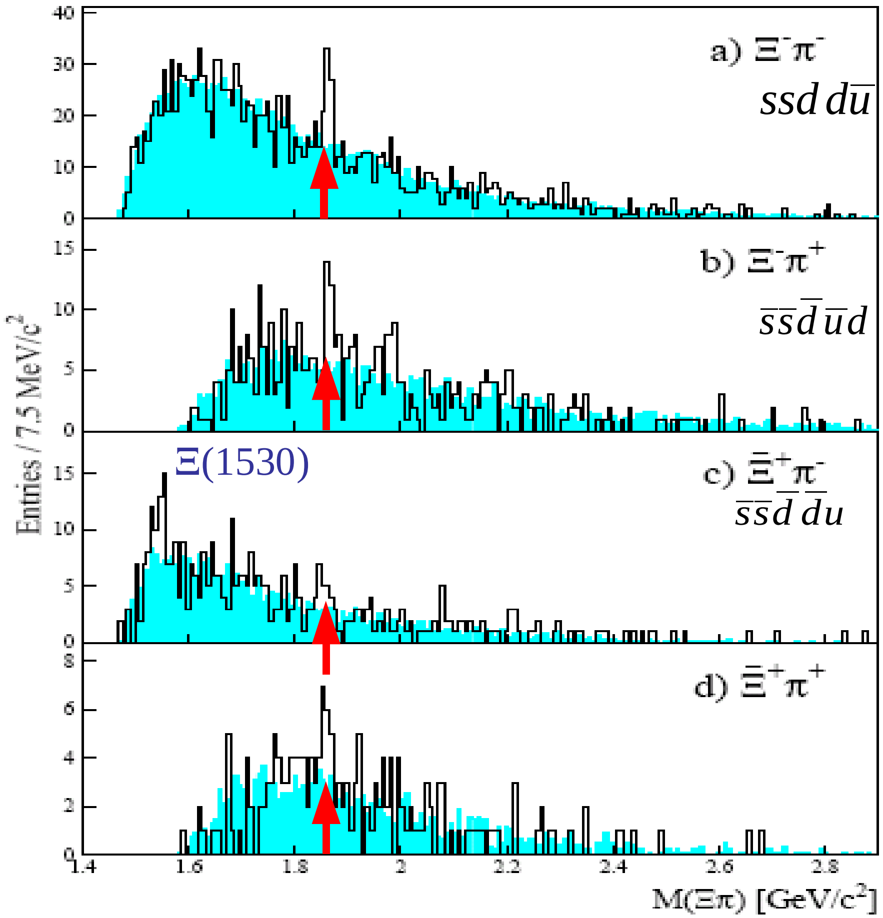
Pentaquarks at CDF

The cousin of Θ^+: Ξ^{--}

NA49 at CERN SPS (hep-ex/0310014)

Observed in $\Xi\pi$ mass, N=67.5 events

m = 1.862 ± 0.002 GeV

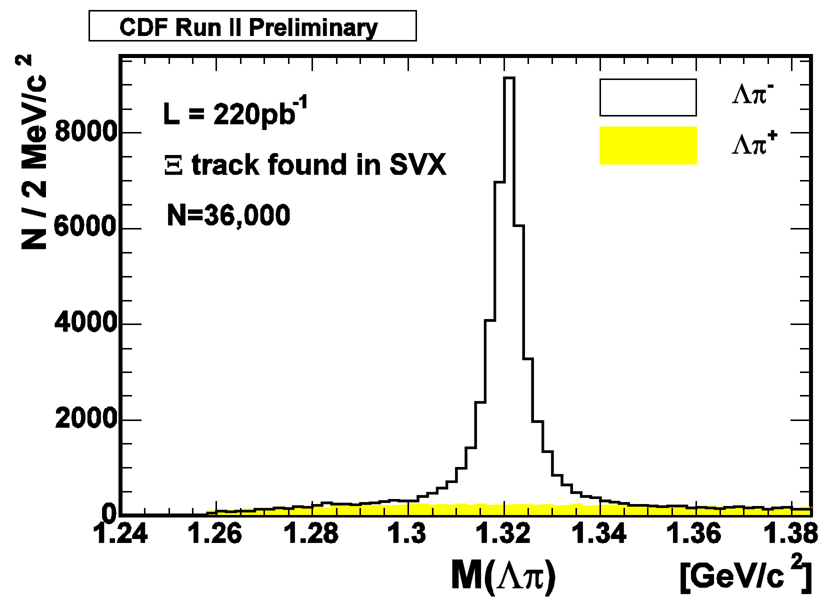


Search for Ξ(1860) at CDF:

- **Search for**

$$\Xi^{--}_{3/2} \rightarrow \Xi^-\pi^-, \quad \Xi^0_{3/2} \rightarrow \Xi^-\pi^+$$

- **CDF developed dedicated tracking of long-lived hyperons in Si. detector**
- **Clean sample of 40k Ξ (x20 stat. NA49)**
- **Use established $\Xi(1530)^0 \rightarrow \Xi^-\pi^+$ as calibration signal**

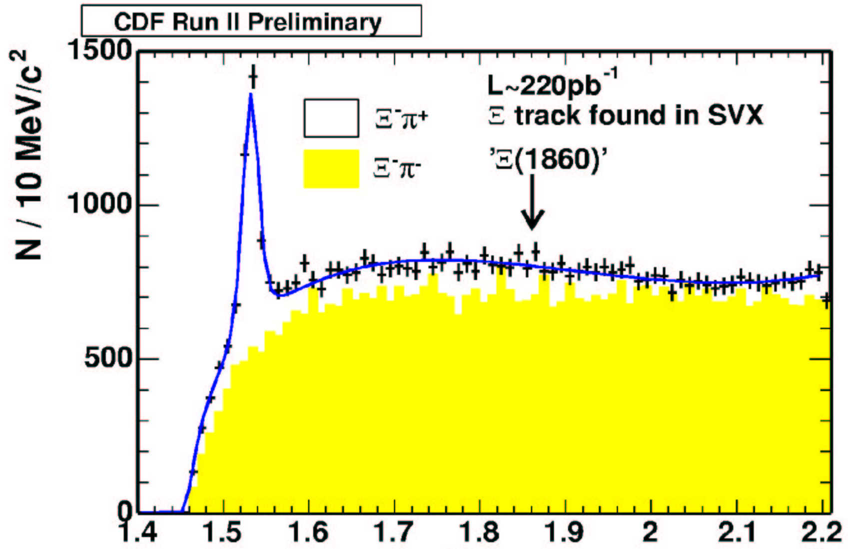


Pentaquarks at CDF

Search for Ξ(1860) at CDF:

- No evidence for narrow signal found in 2 data samples (had. track & jets)

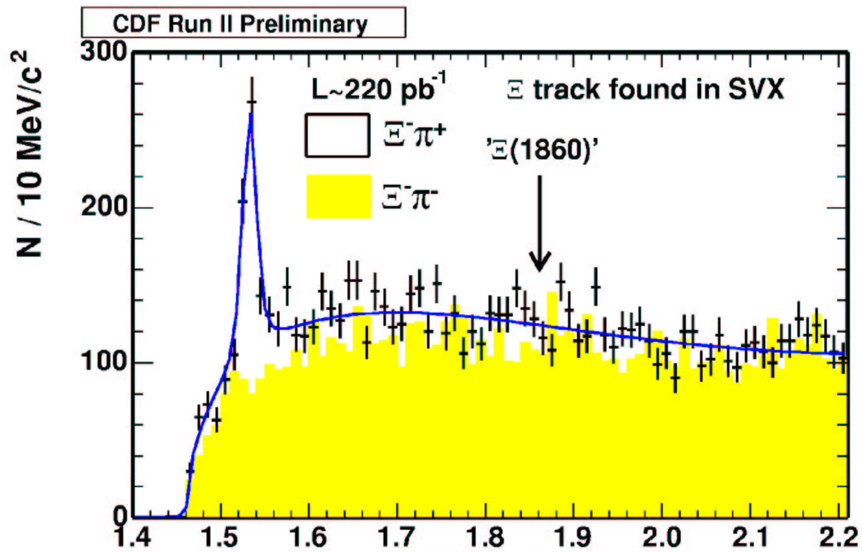
	NA49	CDF (90%CL)
$\frac{N(\Xi^-\pi^+)}{N(\Xi(1530))}$	0.21	< 0.06
$\frac{N(\Xi^-\pi^-)}{N(\Xi(1530))}$	0.24	< 0.03



had. track data

Similar acceptance:

$$A = \frac{\sigma(pp \to \Xi(1530)) \cdot a(\Xi(1530))}{\sigma(pp \to \Xi) \cdot a(\Xi)}$$



jet data

NA49: A ~ 0.068

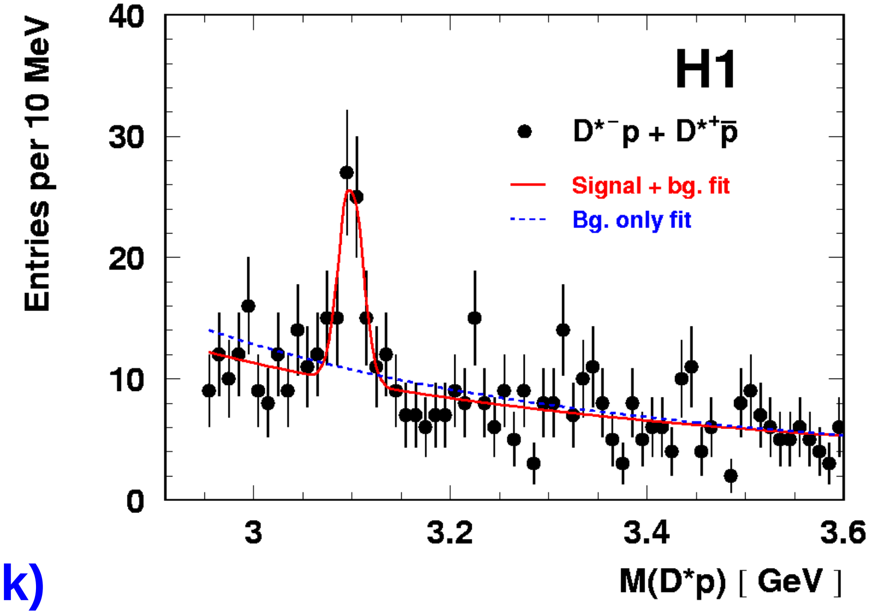
CDF: A ~ 0.061

Pentaquarks at CDF

Search for Charmed Pentaquark

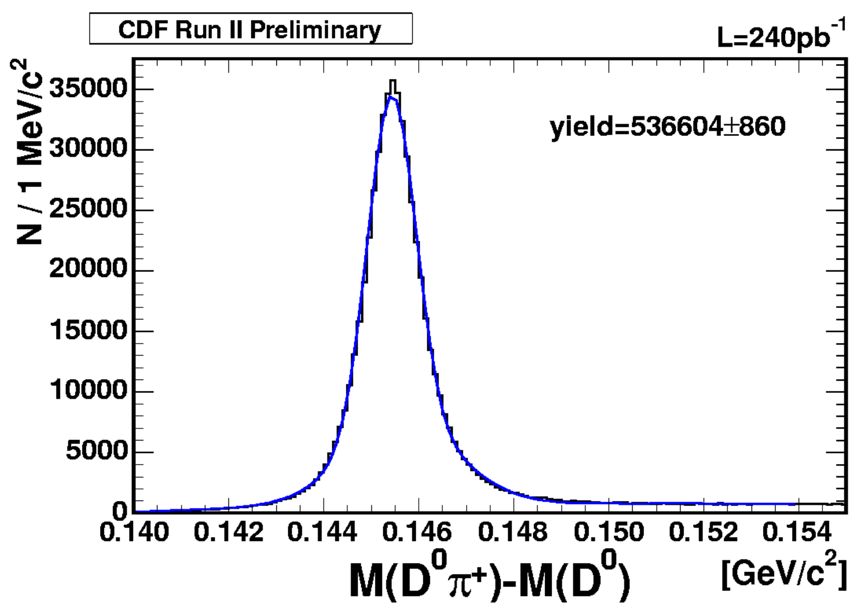
- March 2004: H1 at HERA:
- Evidence for $\Theta_c^0 : |u\,u\,d\,d\,\bar{c}\rangle$
- Reconstructed in $\Theta_c^0 \rightarrow D^{*+}\bar{p}$

  m=3099±3±5 MeV, N=51±11



CDF:

- Large sample of D^{*+} (0.5 mio)
- Use $D^{**} \rightarrow D^{*+}\pi$ as calibration mode (15k)



Pentaquarks at CDF

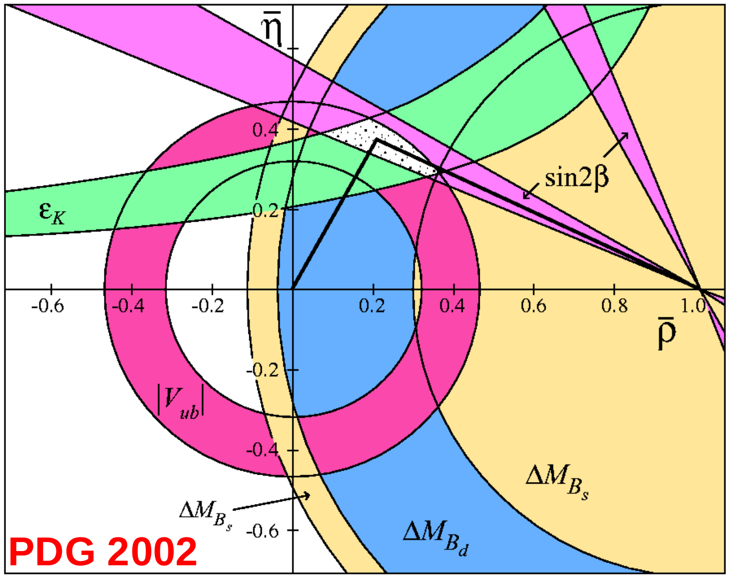
Search for Charmed Pentaquark

- Identify proton using ToF ($p<2.75$ GeV) and dE/dx ($p>2.75$ GeV) (~ 2σ separation each)
- No evidence of charmed pentaquark seen
- Combined upper limit: $\leq$ 29 events (90% C.L.)

The Future

Near Future: B_S Oscillations

Why are we interested in B_s Oscillations?



Near Future: B_S Oscillations

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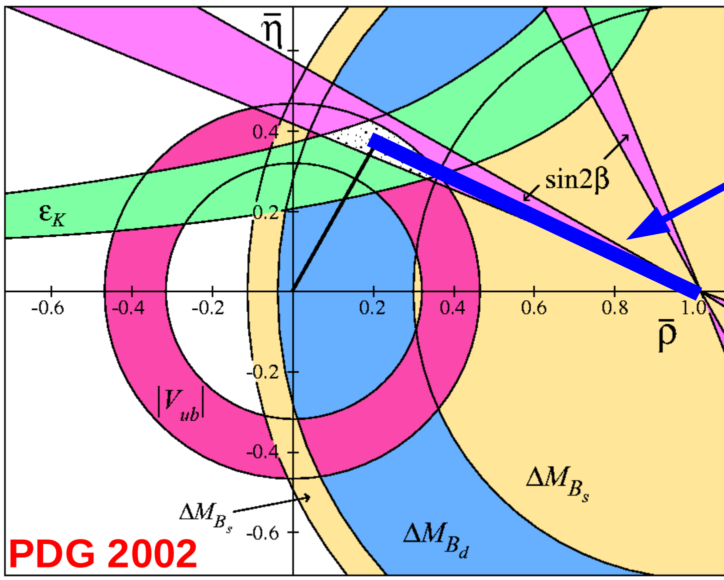
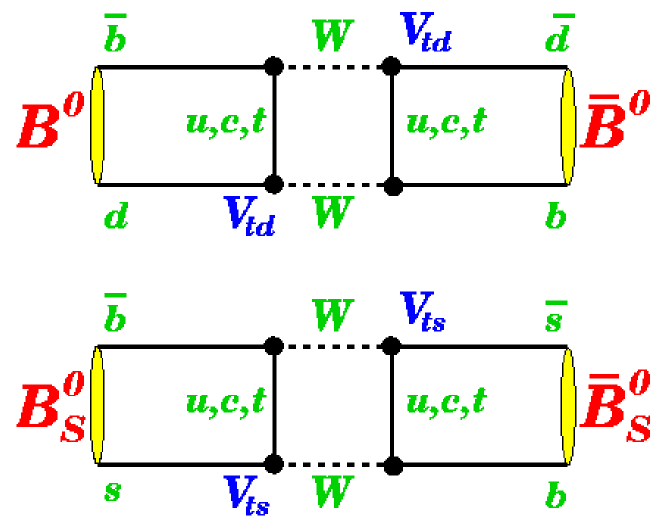


$$\bullet \; \frac{|V_{td}|}{|V_{ts}|}$$



$$\Delta m_d = \frac{G_F^2}{6\pi^2} m_B \, (f_B^2 B_B) \, \eta_B \, m_t^2 \, F\left(\frac{m_t^2}{m_W^2}\right) |V_{tb}^* V_{td}|^2$$

Experiment — Lattice QCD — CKM elements

[redacted] from Lattice

Want to measure:

$$\frac{\Delta m_S}{\Delta m_d} = \frac{m_{B_S^0}}{m_{B^0}} \frac{f_{B_S^0}^2 B_{B_S^0}}{f_{B^0}^2 B_{B^0}} \frac{|V_{ts}|^2}{|V_{td}|^2}$$

B_s Oscillations

Tevatron only place to observe B_s oscillations until LHC

Difficult measurement (give CDF prospects):

Current conditions: fully rec. $Bs \rightarrow Ds\pi$

- S = 1600 events/fb-1
- S/B = 2/1
- εD^2 = 4 % (SLT+SST+JQT)
- σ_t=67 fs

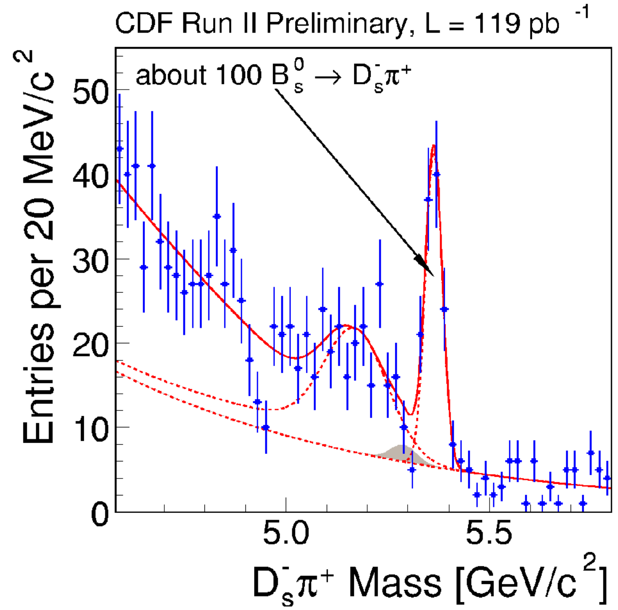
Short term 500 pb^{-1} (no improvement up to 2005)

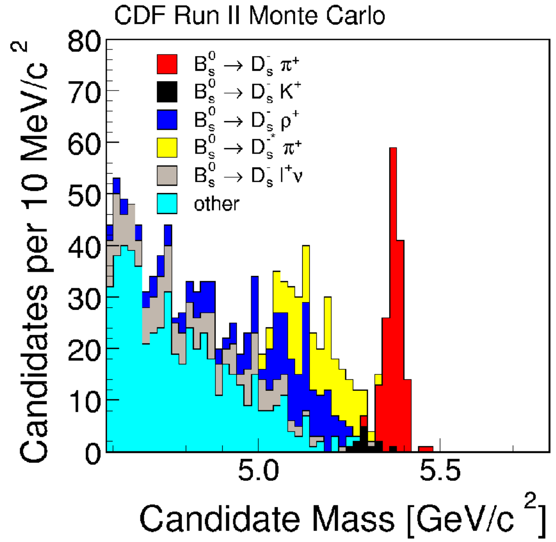
- 2σ (for Δm_s = 15 ps-1)
- Reach the current indirect limit.
- Cover the Standard Model favored range

Beyond SM favoured range (conserv. improvements)

- 5 σ if Δms = 18 ps^{-1} with 1.8 fb-1
- 5 σ if Δms = 24 ps^{-1} with 3.2 fb-1

CDF & D0 work towards B_s mixing with high priority





Towards B_s Oscillations

First Measurement of B^0 oscillations at D0

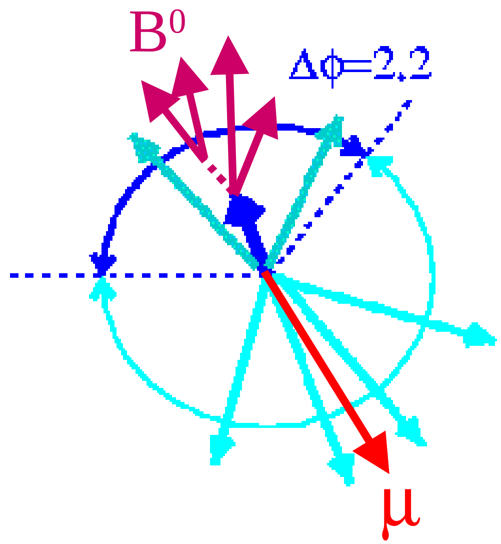
Use sample of semileptonic B -> $D^* \mu$ decays

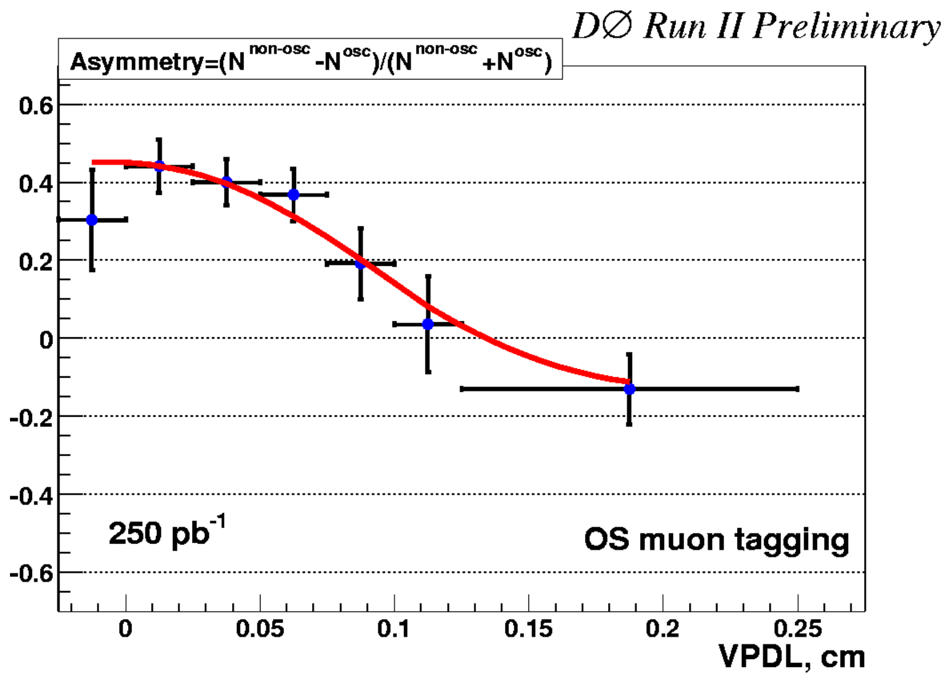
Tagging procedure

- opposite side tight muon
- muon p_T > 2.5 GeV/c
- cos $\Delta\phi(\mu, B)$ < 0.5

Fit procedure

- Binned χ^2 fit





Preliminary results:

Δm_d = 0.506 $\pm$ 0.055 $\pm$ 0.049 ps^{-1}

Tagging efficiency: 4.8 +/- 0.2 %
Tagging dilution: 46 +/- 4.2 %

One of the best measurements at a hadron collider

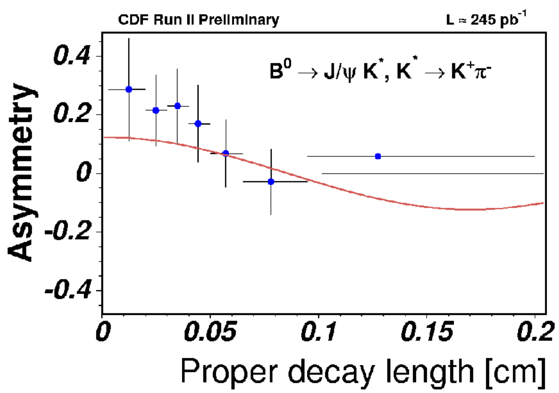
Towards B_s Oscillations

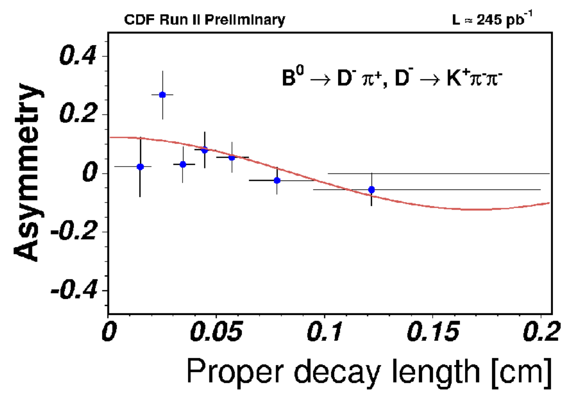
First Run II measurement of B^0 oscillations at CDF

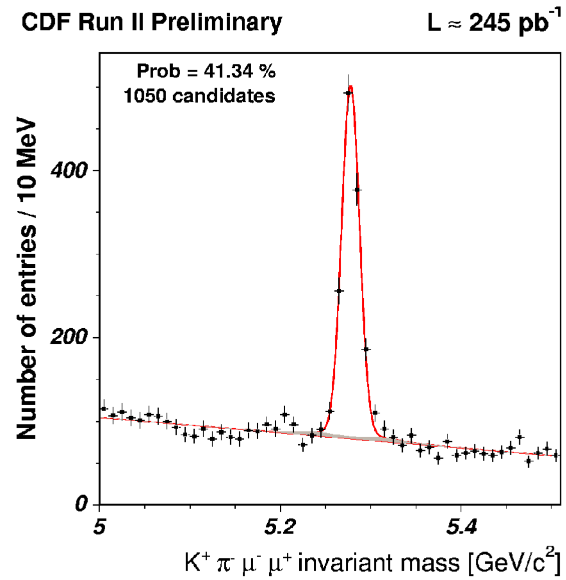
Use fully reconstructed $B^0 \to J/\psi K^*$ & $B^0 \to D^- \pi^+$

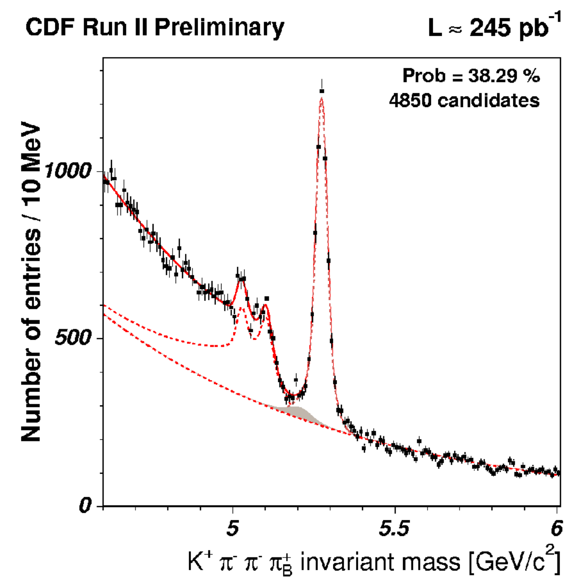
Use same side tagging

$$\Delta m_d = 0.55 \pm 0.10 \pm 0.01 \ ps^{-1}$$









CDF flavour tagging studies:

Same-side (B^0)	$\varepsilon D^2 \approx (1.0 \pm 0.5)\%$
Muon tagging	$\varepsilon D^2 \approx (0.7 \pm 0.1)\%$
JQT	$\varepsilon D^2 \approx (0.42 \pm 0.02)\%$
OS-Kaon	in progress

The Future

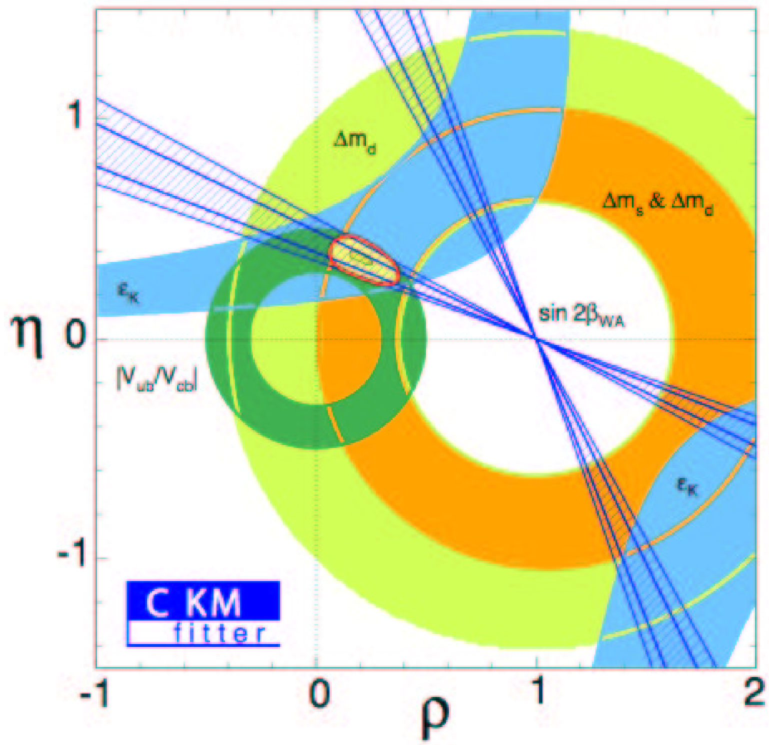
Goal of present & future B physics:

- **Test flavour changing interactions in all possible ways**

  => *Theoretically clean modes versus experimental accessibility*

- **Measure sides and angles of CKM triangle in many ways**

  => *Overconstrain triangle*



The Future

Goal of present & future B physics:

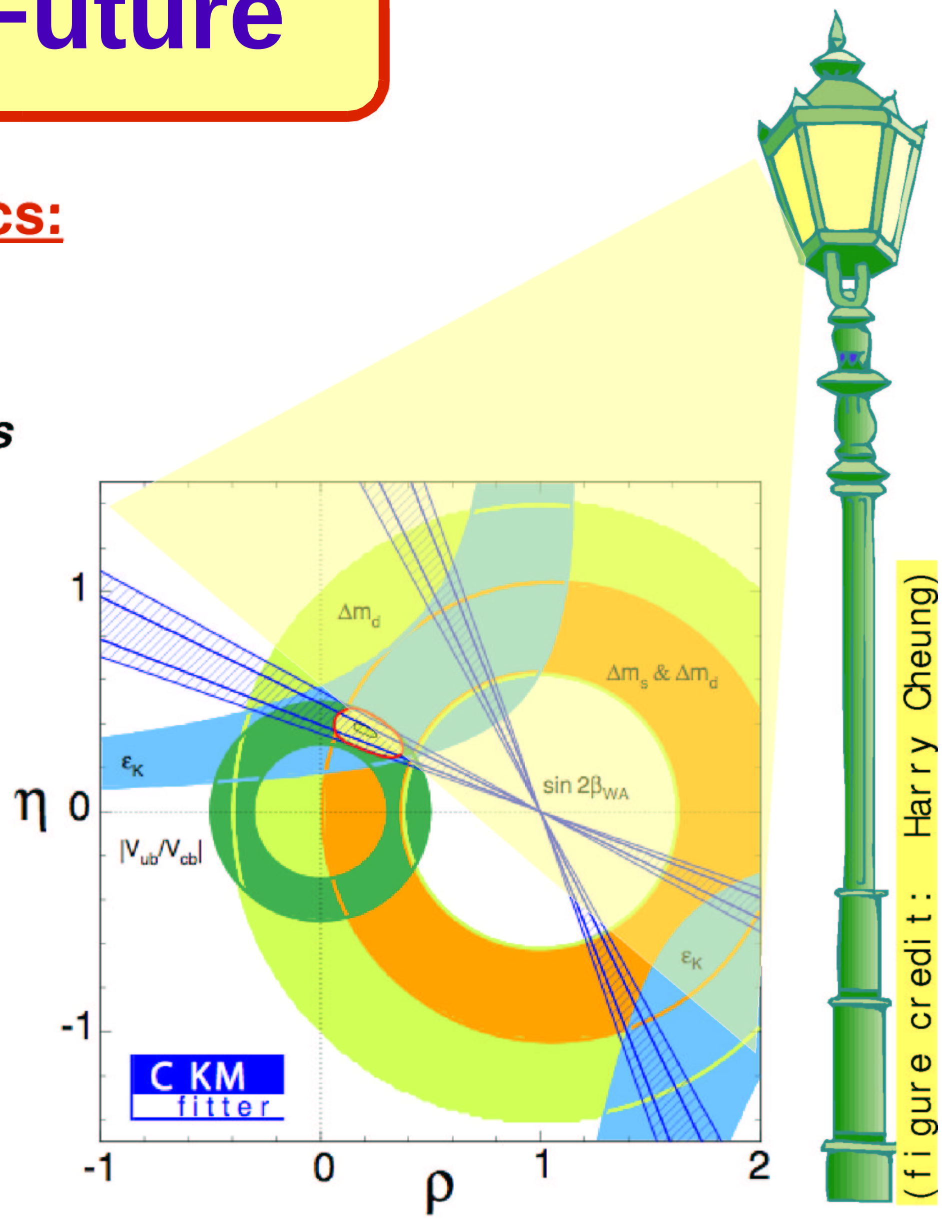
- Test flavour changing interactions in all possible ways

  => Theoretically clean modes versus experimental accessibility

- Measure sides and angles of CKM triangle in many ways

  => Overconstrain triangle

The case for BTeV & LHCb



Overview of BTeV and LHCb

- BTev & LHCb are forward spectrometers at hadron colliders.
  - LHCb: LHC at CERN, first data 2007.
  - BTeV: Tevatron at Fermilab, first data 2009
- Fundamental idea: Separate b/c from background via decay length
  - This introduces the least bias.
  - Try to do this as early as possible in the trigger.
- Large samples of b quarks are available:
  - BTeV: ~2×10^{11} b-bbar pairs per year .
  - LHCb: ~1×10^{12} b-bbar pairs per year .
- e^+e^- $\Upsilon(4S)$ at $\mathcal{L} = 10^{34}\ cm^{-2}\ s^{-1}$ yields ~2×10^8 B's per year.
  - Require $\mathcal{L} = 10^{36}\ cm^{-2}\ s^{-1}$ to be competitive.
- B_s , B_c & b-baryons are produced at hadron machines

Overview of BTeV and LHCb

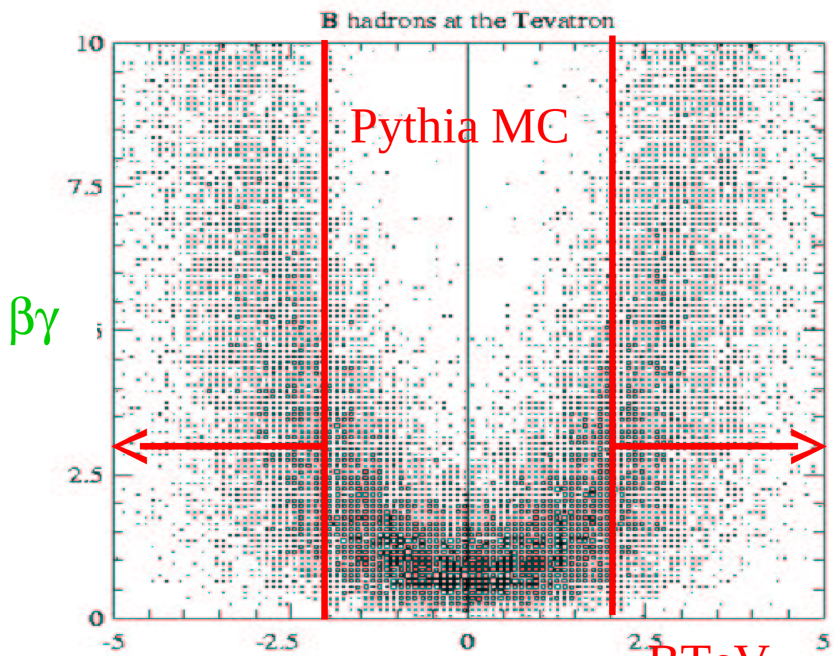
Accelerator parameters and cross sections

	BTeV	LHC-b
Location	Tevatron, Fermilab	LHC, CERN
E_{CM}	2 TeV	14 TeV
Collisions	p-pbar	p-p
σ(b-bbar)	100 μb	500 μb
σ(b-bbar)/σ(visible)†	1/375	1/160
σ(c-cbar)	1.0 mb	3.5 mb
σ(c-cbar)/σ(visible)†	1/40	1/25
Peak Lumi	2×10^{32} cm^{-2} s^{-1}	2×10^{32} cm^{-2} s^{-1}
Integrated Lumi	2 fb^{-1} / year	2 fb^{-1} / year
b-bbar pairs/year	2×10^{11}	10×10^{11}

† Using σ(b-bbar)/σ(total)=1/500 from BTeV TDR and σ(visible)/σ(total)≈ 0.75 from Tevatron Run II handbook.

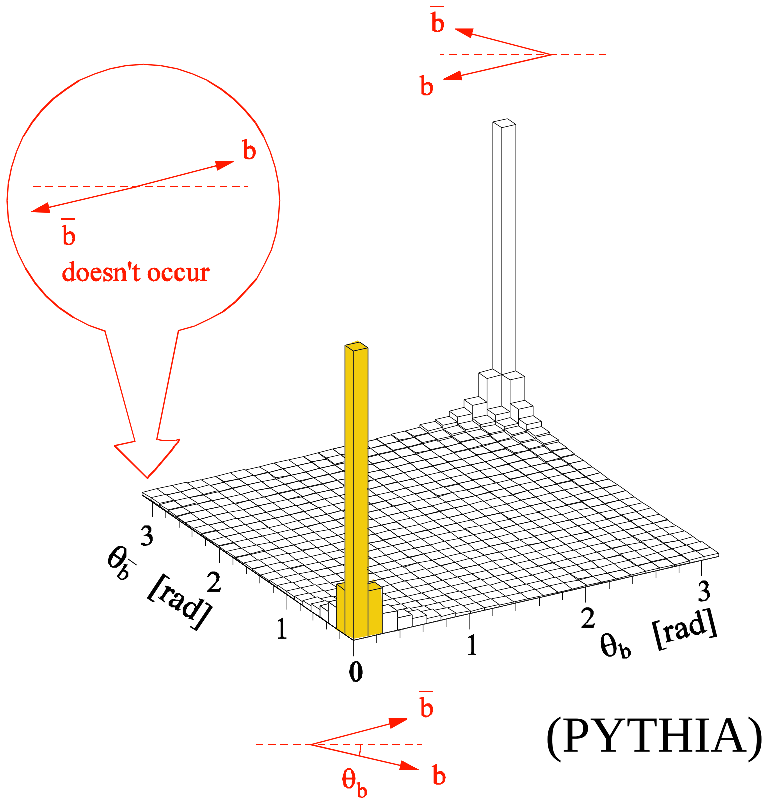
Overview of BTeV and LHCb

Why a forward detector?



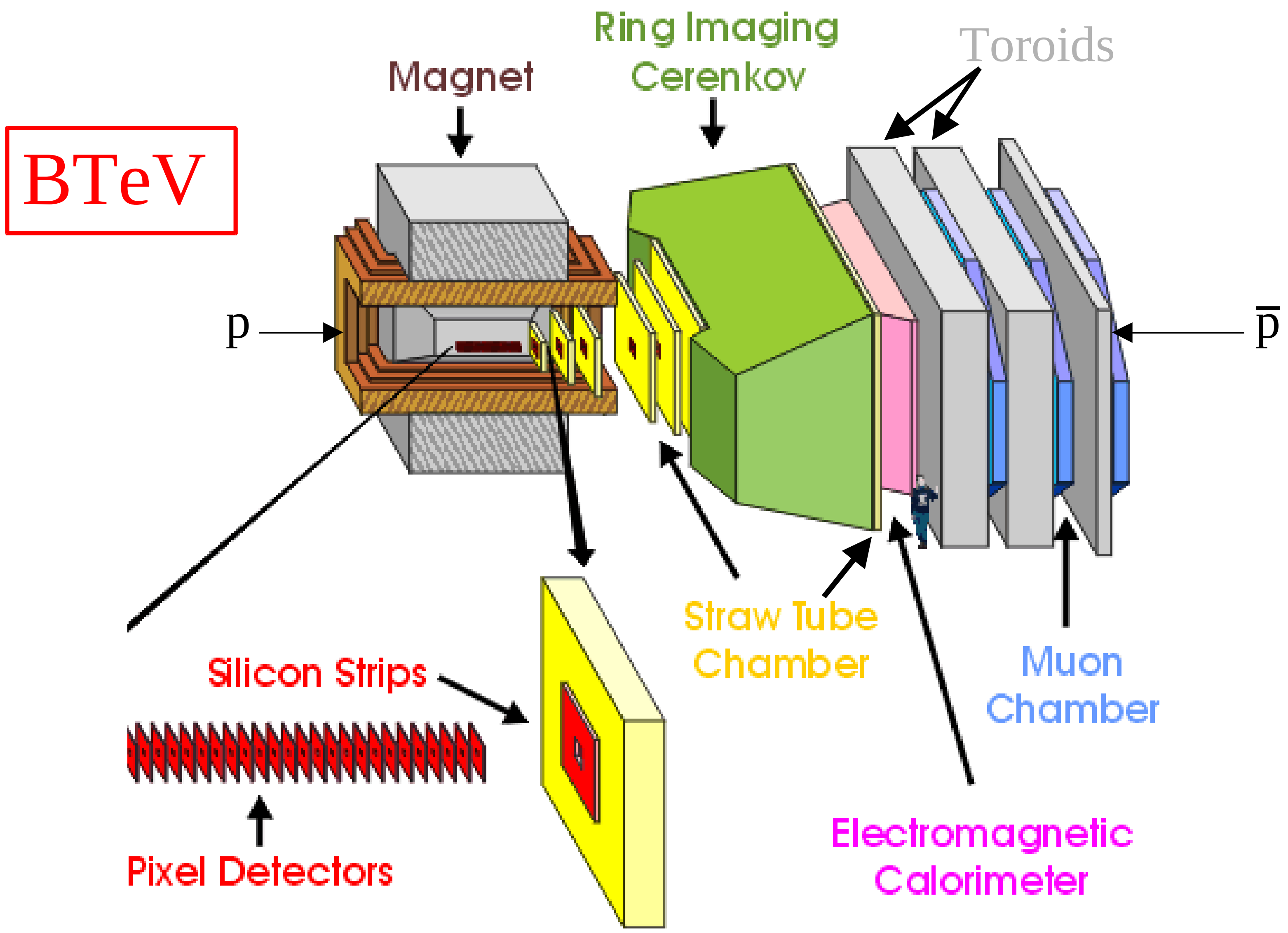
- **Higher momentum**
  - **Longer decay lengths**
  - **Less multiple scattering**
- **Use decay length to separate heavy flavour from background.**

b–b̄ correlation



- **High probability for both b hadrons to be in the acceptance.**
  - **Critical for flavour tagging.**

BTeV Detector

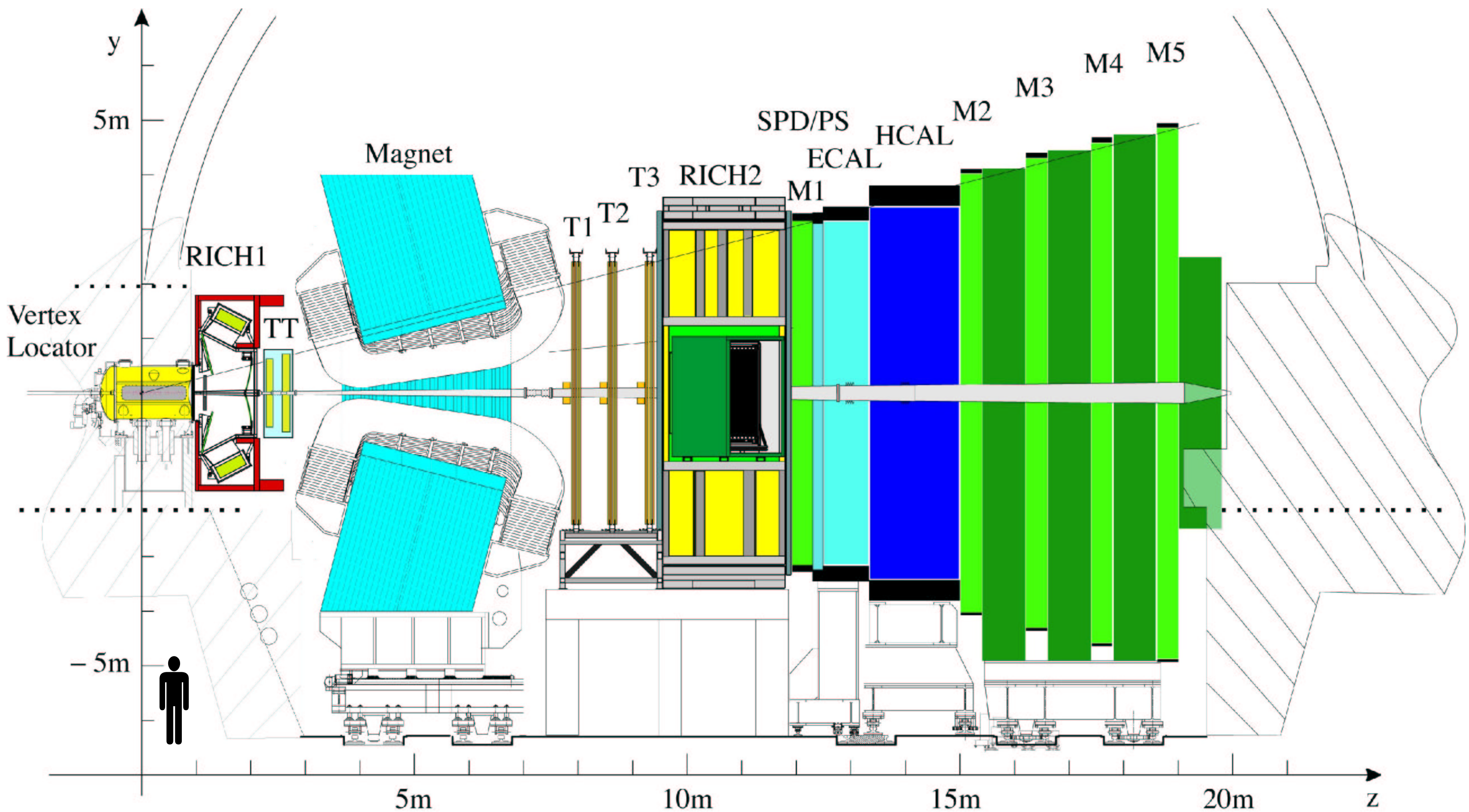


BTeV Detector

Key design features of BTeV:

- Magnet on the IR
  - Allows momentum measurement in the trigger.
- Precision vertex detector
  - Planar pixel arrays.
- Vertex trigger at Level 1.
  - Can trigger on final states with only hadrons.
- $PbWO_4$ Calorimeter
  - γ and π^0 reconstruction.
- Strong Particle ID
  - Ring Imaging Cerenkov (RICH) detector.
  - Hadron and lepton ID!
  - Background rejection.
  - Flavor tagging.
- Excellent muon ID system
  - Redundant triggering of final states with muons.
- Fast, high capacity DAQ.
  - Can record a significant fraction of all B decays.
- Originally 2 arms
  - Lost one arm due to funding constraints.
- Design bunch crossing was 132 ns - now 396 ns
  - Implies 3 times the pile up for the same luminosity.
  - Studies indicate degradations are ~10% in yield for same S/B.

LHCb Detector



LHCb Detector

LHCb Re-Optimization:

- Sept. 2003: TDR for a reoptimized detector.
- Reduce material
  - Thinner devices and supports
  - Remove unneeded tracking and VELO stations.
  - Reduce multiple scattering and particle loss due to interactions in material.
- Remove magnet shield to allow B field in region of the Trigger Tracker (TT) and RICH 1.
- L1 Trigger:
  - Tracks use VELO + TT hits.
  - Crude momentum measurement from bend in the fringe field.
  - Low momentum tracks, which can have large scattering, do not contaminate the detached track trigger decision.

Comparison of BTeV and LHCb

Some technology choices:

	BTeV	LHCb
Magnetic field integral	2.6 T-m (center to end)	4 T-m (full length)
Vertex Tracker	Pixels	Silicon Strips
Downstream Tracker	Si Strip + Straws Tubes	Si Strip + Straw Tubes
Particle ID	RICH; 2 Radiators C_5F_{12}, C_4F_{10}	2 RICH; 3 Radiators Aerogel; C_4F_{10}; CF_4
EM Cal	$PbWO_4$ Crystals	Shashlik: Pb-Scint
Hadronic Cal	-	Fe + Scintillating tiles
Muon System	Stainless steel prop tubes	MWPC: wire + cathode
Angular Acceptance	10 – 300 mr	15 – 300 mr

BTeV and LHCb Trigger

BTeV

- Beam crossing 2.5 MHz
- L1: 50 kHz
  - Find tracks in pixels.
  - Find vertices.
  - Cut on impact parameters
- L2: 5 kHz
  - Refine tracks in pixels
  - Refine vertices
  - Cut on impact parameters
- L3: 2.5 to 4 kHz
  - Rate depends on event size.
  - May use all detector info
  - Algorithms TBD. Goal is to be as open as possible. Will select some final states but will also accept more.
- Independent di-muon at L1.

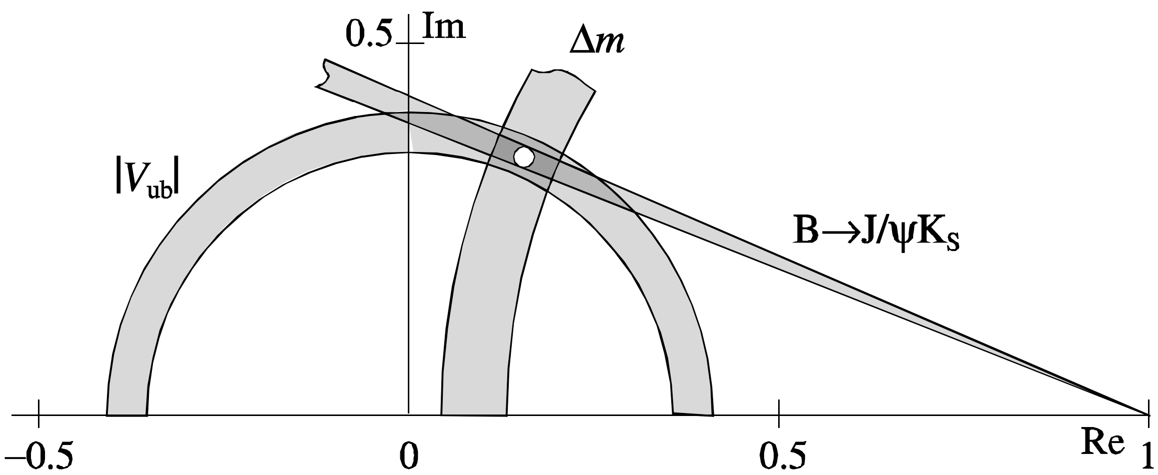
LHCb

- Beam crossing: 40 MHz
  - 10 MHz with inelastic interactions
- L0: 1 MHz
  - Find clusters in calorimeter
  - Find tracks in μ system.
  - Cut on P_T (1 to 3 GeV).
  - Reject pile up.
- L1: 40 kHz
  - Find tracks using, VELO, TT and L1 info.
  - Find primary vertex.
  - Cut on and P_T and impact parameter of tracks.
- HLT: 200 Hz
  - May use all detector info.
  - Select final states.

Physics with BTeV and LHCb

Want to overconstrain CKM triangle

Possible scenario:



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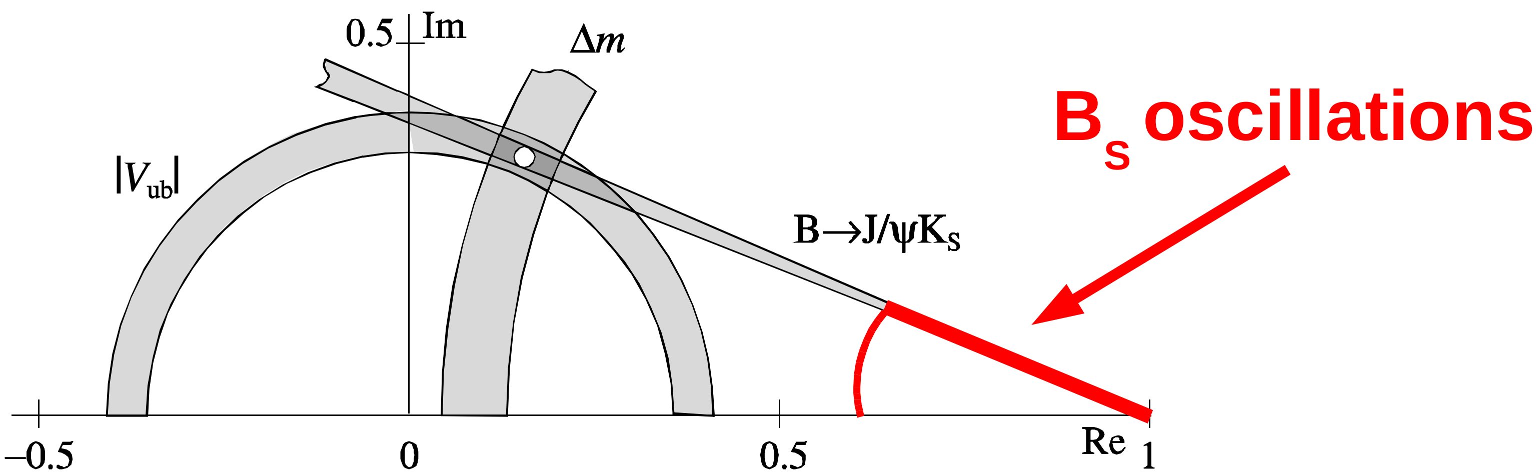
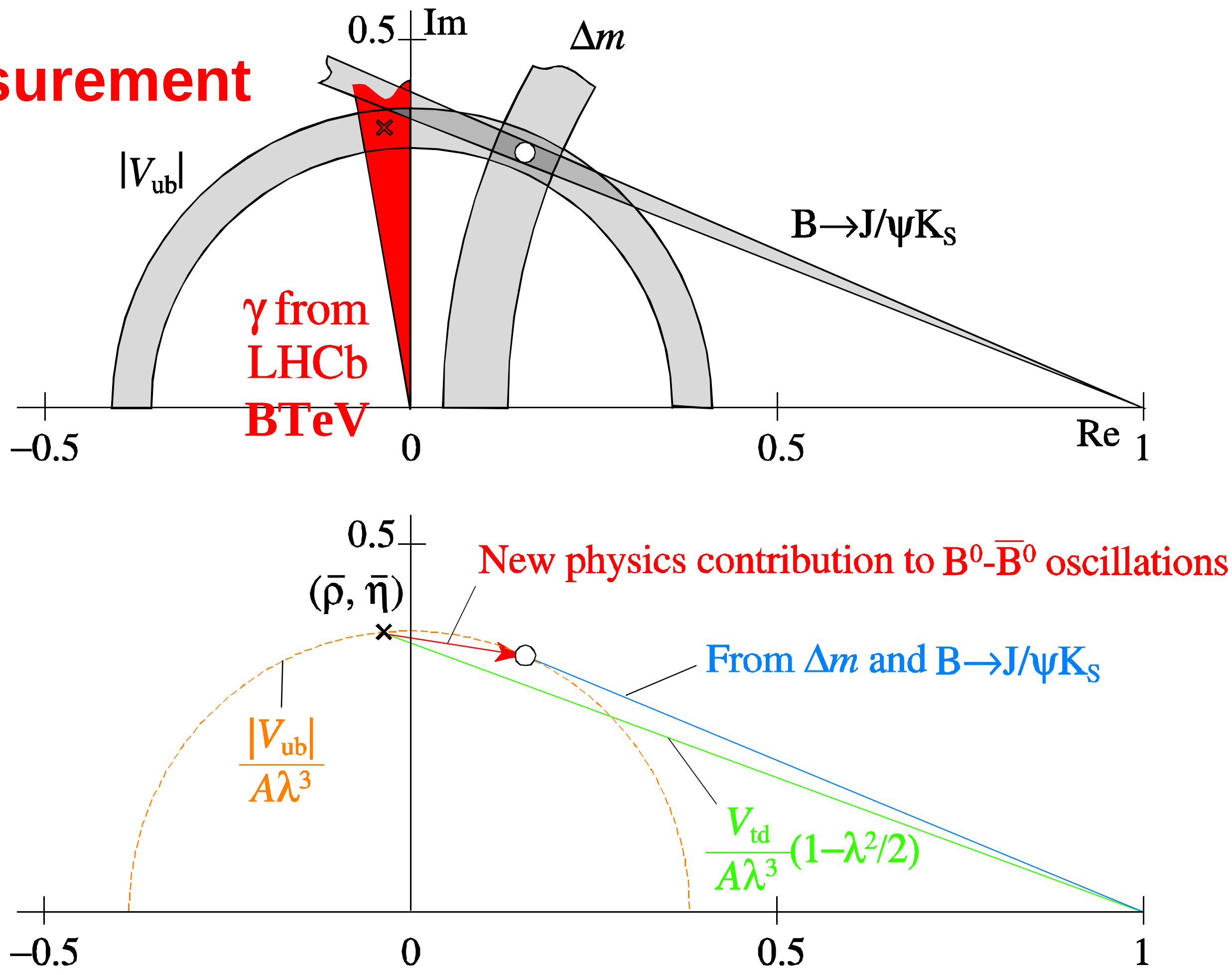


Physics with BTeV and LHCb

Want to overconstrain CKM triangle

Possible scenario:

γ measurement



Physics with BTeV and LHCb

Summary of Physics Reach (10^7 s)

Reaction	Parameter	LHC			BTeV		
		Yield	S/B	Sensitivity†	Yield	S/B	Sensitivity†
$B^o \to \pi^+\pi^-$	Asym	26,000	>1.4		14,600	3	0.030
$B^o \to J/\psi K_S$, $J/\psi \to \ell^+\ell^-$	$\sin(2\beta)$	241,000	1.2	0.02	168,000	10	0.017
$B_s \to D_s K^-$	$\gamma - 2\chi$ $\approx\gamma$	5,400	>1	14^o	7,500	7	8^o
$B_s \to D_s \pi^-$	x_S	80,000	3	<100†	59,000	3	<75†

† Sensitivity means either the error on the parameter or the limiting value which we can measure.

† Upper limit for a measurement with 5 σ significance. $\sigma(x_S)$ <0.02 for most x_S.

Warning: No check made that both use same assumptions about branching ratios.

Physics with BTeV and LHCb

Summary of Physics Reach (10^7 s)

Reaction	Para-meter	LHC			BTeV		
		Yield	S/B	Sensitivity†	Yield	S/B	Sensitivity†
$B^- \to D^o (K^+\pi^-) K^-$	γ				170	1	13^o
$B^- \to D^o (K^+K^-) K^-$	γ				1,000	>10	
$B^0 \to D^0(K\pi)K^{*0}$		3,400	>2.0				
$B^0 \to D^0_{CP}$bar K^{*0} $B^0 \to D^0_{CP} K^{*0}$bar	γ	590	>0.35	7^o to 9^o depending on γ.			
$B^- \to K_S \pi^-$	γ				4,600	1	$< 4^o$ + theory errors
$B^o \to K^+\pi^-$	γ				62,100	20	

† Sensitivity means either the error on the parameter or the limiting value which we can measure.

Warning: No check made that both use same assumptions about branching ratios.

Physics with BTeV and LHCb

Summary of Physics Reach (10^7 s)

Reaction	Para-meter	LHC			BTeV		
		Yield	S/B	Sensitivity†	Yield	S/B	Sensitivity†
$B^o \to \rho^+\pi^-$	α	4,400	0.14		5,400	4.1	~4^o (For 1.4 years)
$B^o \to \rho^o\pi^o$	α				780	0.3	
$B_s \to J/\psi\ \eta$, $J/\psi \to \ell^+\ell^-$	$\sin(2\chi)$	7,000	>0.2		2,800	15	0.024
$B_s \to J/\psi\ \eta'$, $J/\psi \to \ell^+\ell^-$					9,800	30	
$B_s \to J/\psi\ \phi$	$\sin(2\chi)$	120,000		0.06†			
$B_s \to J/\psi\ \phi$	$\Delta\Gamma_S/\Gamma_S$			0.02†			

† Sensitivity means either the error on the parameter or the limiting value which we can measure.

† Typical values. Exact values depend on assumptions about x_S, χ, $\Delta\Gamma_S/\Gamma_S$ and R_T.

Warning: No check made that both use same assumptions about branching ratios.

Conclusions

- Wealth of new B physics results from CDF & D0
  - D0 demonstrates very competitive B physics program
  - Negative pentaquark searches from CDF
- CDF & D0 work towards measurement of B_S oscillations
- LHC-b well on the way towards first data in 2007
  - Many components already at CERN
  - Can do great physics with initial LHC luminosity
- BTeV expects first data in 2009
  - Funding (CD-0) approved by DOE
  - R&D is already well advanced. Final decisions in 2004

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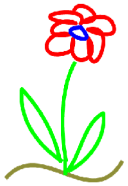
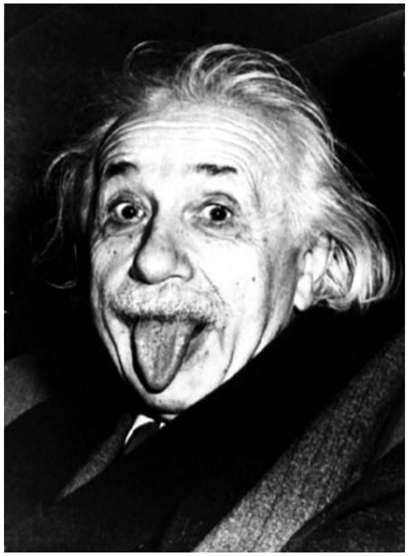
"Anyone who keeps the ability
to see beauty
never grows old."

Franz Kafka



Conclusions



"God doesn't play dice with the universe."
(Albert Einstein)

"If only god would give me some clear sign!
Like making a large deposit in my name at a Swiss bank."
(Woody Allen)